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ABSTRACT

The construction of cognitive tests is largely based on a Thurstonian model of the structure of the intellect, with test content described in terms of loadings on broad constructs called factors. Knowledge of factorial content of a test does not necessarily correspond to knowledge of mental activities elicited by test performance. Modern cognitive theory, on the other hand, attempts to describe basic human information processing, but may not adequately accommodate individual differences. The integration of psychometrics with information processing theory would benefit both disciplines. In educational assessment, evaluations done at a number of points in time during acquisition of competence could lead to better understanding of cognitive processes (as opposed to cognitive products alone). This paper reviews theory relevant to these related disciplines and proposes six assessment methodologies: (1) assessment of metacognition; (2) faceted tests; (3) measures of structures of knowledge; (4) error analysis; (5) learning potential and transfer; and (6) assessment of information processing styles. Implications are considered for adaptive education, for basic research (especially cross-cultural) on strategies of problem solving and task execution, and for assessment in multicultural settings such as South Africa. (Author/LPG)

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Special Report PERS-420 1987

The future of cognitive assessment

Terence R Taylor

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The Future of cognitive assesment

Special Report PERS-420

The future of cognitive assessment

T R Taylor

Pretoria
Human Sciences Research Council
1987

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EKSERP

Die konstruksie van kognitiewe toetse word grootliks op Thurstone se model van intellekstruktuur gebaseer. Die inhoud van toetse word beskryf in terme van ladings op wye konstrukte wat as faktore bekend staan. Faktore is egter empiriese eerder as teoretiese konstrukte; inligting i.v.m. die faktorinhoud van 'n toets lei nie tot inligting i.v.m. die werklike denkaktiwiteite wat van die proefpersoon gedurende die afle van die toets vereis word nie.

Moderne kognitiewe teorie beskryf menslike funksionering in terme van basiese informasieprosesse; die teorie maak egter nie voldoende voorsiening vir individuele verskille nie. Die integrasie van psigometrika en informasieverwerkingsteorie sal beide velde tot voordeel strek.

Evaluering is gewoonlik daarop gerig om vaardigheid in 'n gegewe veld op 'n sekere tydstip te meet. Evaluerings wat op verskillende tye in die loop van die aanleer van 'n vaardigheid gemaak word, voorsien waardevolle bykomende inligting oor 'n individu se kognitiewe funksionering.

In hierdie verslag word 'n oorsig van die teorie wat met so 'n benadering verband hou, aangebied en ses nuwe evalueringsmetodologiee word voorgestel. 'n Nuwe rol word vir evaluering voorgestel - beide in aanpassende onderwys en in basiese navorsing (veral kruis-kulturele navorsing) oor strategiee van probleemoplossing en taakvoltooiing.

ABSTRACT

The construction of cognitive tests is largely based on a Thurstonian model of the structure of intellect. The content of tests is described in terms of loadings on broad constructs called factors. Factors are, however, empirical rather than theoretical constructs; knowledge of the factorial content of a test does not lead to knowledge of the actual mental activities demanded of the subject when doing the test.

Modern cognitive theory describes human functioning in terms of basic information processes; the theory has, however, been rather unsuccessful in accommodating individual differences. The integration of psychometrics with information processing theory would benefit both disciplines.

Assessment is usually aimed at evaluating competence in a given domain at one point in time. Evaluations done at a number of points in time during acquisition of competence provide valuable additional information about the individual's cognitive functioning. Hence, educational psychology should also be integrated with psychometrics and information processing theory into an overall approach to cognitive functioning.

In this report the theory relevant to an approach of this kind is reviewed, and six new assessment methodologies are proposed. New roles are suggested for assessment, in adaptive education and in basic research (especially of a cross-cultural nature) into strategies of problem solving and task execution.

1.0 INTRODUCTION

Like the motor car, psychological tests have been in existence for just over one hundred years. In 1882 Galton established a laboratory in London where, for a small fee, people could be tested on visual acuity and reaction-time tasks (Galton regarded simple sensori-motor reactions to be indicators of the more profound intellectual capabilities of humans). It is with some justification that Galton can be regarded as the father of individual differences psychology and testing.

Like the motor car, psychological tests have changed relatively little in their fundamentals since the 1920's and 1930's. By the end of this period, Thurstone had developed his multifactorial model of human intellect, which formed the basis for the development of a whole range of tests of cognitive ability. Personality assessment was well under way by the Nineteen Thirties and classical test theory was advancing. Relatively few noteworthy innovations occured after this period.

Certain recent developments in testing might appear to be revolutionary, but this is not the case. The implications of tailored testing are exciting, but these are of a mainly practical nature (fewer items will be needed to evaluate an individual's performance on a given psychological dimension with a given level of accuracy). Tests will not change in their fundamentals as a result of this development, just as the addition of a turbo-charger (another modern development) does not change the fundamental nature of the internal combustion engine. Similarly, research into bias and fairness in testing is not likely to result in the creation of radically new types of test. Details of some tests are likely to change (certain items may have to be replaced), but in general the tests are likely to look much the same as they always have.

The lack of innovation in test construction would not matter if tests were giving psychologists all the information they needed to know about their subjects' mental functioning. Unfortunately this is not the case. Current psychological measures give only a gross description of mental characteristics, just as engine power describes an engine only grossly. Engine power is nevertheless a very useful and appropriate index of engine functioning; it is well defined and tells one quite a lot about what to expect of the car on the road in terms of performance. The same cannot be said of human ability constructs. These constructs are usually not clearly defined; but worse, their operationalization in measurement instruments leaves much to be desired. The nature of the contents of psychological measures is poorly understood in most cases. Unlike measures of engine power, these measures do not give a good indication of performance "out there" (outside the laboratory or testroom).

Tests were initially developed in First World countries with relatively homogenous societies. Traditional ability measures can be applied more appropriately in these countries than in a multicultural country like South Africa for at least two reasons.

One, in First World populations most abilities are likely to have reached their asymtote, or be close to it, by early adulthood. Almost all individuals in First World societies should have had the opportunity to exercise these abilities to the point where their performance level is likely to have stabilized. A low score hence implies a low plateau, not a partially acquired skill. The score obtained by an individual reflects an upper limit of competence, and therefore can be taken as a reasonably accurate index of his capacity. In societies where the testee population is drawn from a diversity of backgrounds, on the other hand, the assumption cannot be made that all individuals have reached their ability plateaus. Less advantaged groups, in particular, are likely to contain members who are still on the steep part of the curve, due to poor education and lack of opportunity. If selection and placement decisions are made on the assumption that test scores reflect an ability asymptote, injustice is done to testees who are from a disadvantaged background, or from a cultural background in which the ability in question was not required and therefore not exercised.

Two, in a culturally homogenous society, the strategies and styles used to perform a given task tend to be more uniform across the population than is the case in a heterogeneous society. Individuals in the former type of society therefore tend to do test items in a similar way and to do tasks (for which the tests may be predictors) in a similar way. The psychologist has a reasonable chance of compiling selection and placement test batteries which measure the actual abilities which people in that society use in order to do the tasks in question. In a multicultural society, on the other hand, the psychologist's chance of selecting appropriate tests is much smaller. He may assume, based on a knowledge of his own culture, that a given set of abilities is necessary to do a given task; however individuals from a culture (or subculture) different from his own may use a different set of abilities. The same outwardly visible competence (e.g., passing a certain examination) can often be achieved in different ways, just as two very different computer programs can produce the same output.

The differences between established First World countries and multicultural developing countries like South Africa have been exaggerated in the above discussion in order to make a number of points. Even in First World countries which have well-established and reasonably standardized educational systems, not everyone has reached an ability plateau by late adolescence. Different styles and abilities are no doubt used to do a given task even in the most homogenous societies. Countries like the USA are in any case becoming increasingly culturally heterogeneous and increasingly aware of their heterogeneity. "Our" (South Africa's) testing problems are therefore also "their" problems, but for us the problems are more intense. These problems are beginning to receive attention in the First World; there is even more reason for cognitive, educational, and measurement psychologists to devote their attention to these problems in this country. Appropriate models and instruments must be developed. Although testing is not an endangered activity at present, social and political developments could in the future drive it from the scene if it does not tackle and solve some of its problems and if it does not define a new role for itself. The nature of this new role will be discussed in this report.

The pressure is therefore on quantitative psychologists to address some serious flaws in their traditional approach to measurement. Like Wordsworth's Happy Warrior, however, the aim of these psychologists should be to "turn necessity to glorious gain." The problems mentioned above could be a spur to the development of new types of instrument which overcome the criticisms outlined above, and in the process result in the development of more fine-grained and testee-centred measures based on modern information processing theory.

For many years, psychologists have been talking about the need to integrate the experimental and individual differences genres of psychology. Experimental psychology has been the vehicle for the development of a number of theories of cognitive functioning; over the last decade-and-a-half these have been mainly of the information processing variety. The experimental approach, largely due to the nature of its research model, has tended to ignore individual differences. The individual differences psychologists, as their name implies, have been concerned with creating instruments which can identify differences between people on a number of dimensions, but they have paid relatively little attention to the precise content of the measuring instruments and the processes required to do the tasks set in these instruments. Hence, the one approach's strength is the other's weakness, and vice versa.

The cognitive psychologists have recently become more aware of the need to take individual differences into account. The reason for this is not hard to see. If information processing theory is intended to discover how people actually do certain tasks, it must allow for differences in the way in which different people do these tasks. As we noted above, however, cognitive psychologists feel more at home studying group differences rather than individual differences; it is here where individual differences psychologists can make a contribution.

The task of incorporating information processing concepts into psychological measurement is not easy, because processes are harder to study than products. Conventional measurement is tester-centred. The tester gives the testee a pre-determined set of questions, and desires only one kind of product from the testee: An answer sheet with crosses neatly placed over admissible response options, which can be swiftly and easily marked. In an ability test the only concern of the tester is whether each answer is right or wrong. Having determined this his next step is to convert the set of right and wrong answers into an overall performance score. To do this he usually uses a simple adding procedure which he applies in a standardized manner to all protocols.

The "new" approach to testing is likely to be more testee-centred. This brings a new dimension to the concept of individual differences. Traditionally, the amount of "individuality" allowed in an individual differences measure is about on a par with the amount of individuality allowed in a military establishment, where you are, for instance, allowed to differ from your fellow recruits on only a few dimensions, such as height. In a test designed to measure processes, on the other hand, the testee should be given scope to express his "differentness" from others not only in his capacity to do a set of tasks, but how he goes about doing these tasks. Assessment instruments which measure styles or strategies of task execution (i.e., which address themselves to answering the "how" of performance) give more useful information than those which measure ability levels (i.e., which try to answer the "how much" of performance), because the former can be used effectively for diagnosis.

This last comment leads on to another characteristic which new generation measures should have. Conventional tests are relatively useless in the educational context because they give the educationalist little guidance on how to go about educating each individual in an optimal way. Diagnostic tests can, however, be integrated with education to create a powerful, mutually-informing system. The ultimate aim is to unite testing, instruction, and cognitive psychology into a system sharing a common "language of discourse." In the opinion of the author, the basic elements of this language should not be at the very high level of factorial constructs, nor at the very low level of first-order information processes; they should be at an intermediate level, incorporating constructs which have been called strategies or metaprocesses.

From the title of this report, the reader might be led to expect that the topics covered will be those which are usually associated with psychometrics. If the reader has such an expectation, he will be taken aback by the range of topics touched on in this report. The intention is not to discuss detail modifications and refinements of the status quo, but possible fundamental changes in the nature and role of assessment.

It is for this reason that an orientation chapter has been included (Chapter 2). This chapter is intended to give the reader a context and assist him or her to understand why certain topics have been selected for special attention. Chapter 2 therefore gives a broad overview; Chapter 3, in contrast, "zooms into" issues which appear to be of particular importance to the future of testing. Chapter 3 is a long chapter: It deals with the issues in some detail. As this report is intended to be a working document and not a vague position statement, it is necessary to deal with the issues at the "nitty-gritty" level.

In Chapter 4 a distillation of the material covered in the previous chapter is given and the most promising future directions for testing are discussed. In the final chapter (Chapter 5) the possibilities offered by new directions in testing are considered in terms of the needs which new tests can fulfil and the utility which they may have in a future South Africa. Hence in Chapter 4, the concern is with what is "possible," while in Chapter 5 the concern is with whether instruments flowing from new approaches can be applied in such a way as to be of benefit to society in general (rather than just certain segments of it, as is often the case with conventional tests).

2.0 THE CURRENT PSYCHOLOGICAL CONTEXT

In this chapter we will review developments in certain fields of psychology where important theoretical work is being done. All these fields are in the ascendancy at present: The character of late twentieth century psychology is largely being defined by developments in these areas. Five fields have been selected. There are unquestionably other fields of psychology which equally deserve a place in this chapter; however, only those which may contribute to new insights in the development of assessment theory and methodology have been selected.

The five fields discussed in this chapter are not totally discrete: There are several areas of overlap. Also not all fields are of the same type. "Computerization", for instance, refers to a technology, whereas "Problem Solving" is a class of cognitive task.

This chapter is not intended as an exhaustive review of these five fields. Rather, the intention is to justify the selection of certain topics for further investigation as sources for new ideas in psychological assessment. Therefore this chapter is an orientation chapter, meant to give background and context to the topics which are discussed in the next two chapters.

2.1 COGNITIVE PSYCHOLOGY AND INFORMATION PROCESSING

Over the last fifteen to twenty years, psychology has been increasingly dominated by a cognitive approach. The emphasis has been on man as a processor of information. Being a relatively new science which has not fully established itself, psychology tends to borrow models from other disciplines, especially those that are dominant forces at a given time. It is therefore not surprising that concepts from computer science, and particularly artificial intelligence, have had an impact on cognitive psychology. The "thought processes" of a computer, as embodied in a computer program, are discrete and explicit. Cognitive psychologists adopted the computer metaphor in the expectation or hope of being able to achieve a similar level of explicitness in the description of human information processing.

The shift to a cognitive-information processing perspective of human functioning in psychology is of such a magnitude that it may be regarded as a paradigm shift in the Kuhnian sense (Kuhn, 1970). The strength and pervasiveness of a particular trend can be judged by the number of undergraduate or introductory books written with the trend as its main theme. By this criterion, cognitive and information processing psychology is a major trend; Solso (1979) and Lindsay and Norman (1977) are examples of introductory publications in this domain.

The information processing approach has helped cognitive psychology to move further away from a "black box" conception of human functioning. Testing under the black box model involves eliciting rather gross responses to rather crude and ill-defined inputs, and interpreting these responses in an equally crude way. Analysis based on such data (as is done in factor analysis, for instance) can at best give some indication of the main "circuit boards" in the black box. At worst it can confuse the observer with unexpected and fluctuating output, which occurs partly because the inputs (tests applied to the box) are so gross and "impure". To pursue the black box metaphor for the purposes of illustration, imagine the confusion which would result if one wanted to study current flow through a given circuit, but inadvertently also fed current into other circuits connected to the circuit under study.

Another reason why confusing and uninterpretable results are obtained is that the research is based on the assumption that all black boxes have comparable software and hardware, and differ only in the efficiency of operation. If this assumption is severely violated then studies designed under the comparability assumption are likely to yield uninterpretable and meaningless results. Factor analytic studies which aim to establish a "structure of intellect" suffer from this problem. The imposition of a single model of intellect is simply not possible in many cases because people differ in the way they process information. Factor analytic studies often fail to produce results which can be cross-validated because different samples have different proportions of various types of information processors. Hunt's (1980) investigation into verbal and pictorial representations of stimuli (to be discussed in a later section) clearly illustrates the need to take account of different styles of processing information.

Although the information processing approach can help us to overcome some of the problems encountered with grosser approaches, many difficulties lie ahead. Information processing belongs in a different paradigm from conventional psychometrics. The former offers certain prospects which are not available under the latter, but one should remember that all scientific frameworks give the researcher new insights but simultaneously limit his vision. Early information processing theory which was heavily based on the computer analogy tended to give a mechanistic caricature of how humans supposedly processed information. Later models broadened their perspective to include some of the higher level executive functions which are essential for the successful execution of most tasks. Nevertheless, the information processing approach has to guard against the danger of being too mechanistic and concerned with detail to the exclusion of the "big picture".

A major challenge which lies ahead is to integrate developments in information processing theory with individual differences research. Pellegrino and Glaser (1979) distinguish two main movements in the study of individual differences in information processing: The cognitive correlates approach which seeks to specify the information processing abilities that are differentially related to high and low levels of aptitude or intelligence, and the cognitive components approach which is task analytic and attempts to identify directly the information processing components in tasks which have been generally used to assess mental abilities. In my opinion, both of these approaches are hybrids as they attempt to relate information processing variables to "old-time" measures of individual differences. What is needed is to develop new measures of individual differences which incorporate information processing and stylistic elements and relate these to certain real-world tasks which have been task-analyzed.

The information processing approach has been used in cognitive research in a number of areas, including re-conceptualisations of intelligence (Hunt, 1980; Snow, 1979a; Sternberg, 1982; Vernon, Nador, & Kantor, 1985), analysis of tasks required in cognitive tests (Carroll, 1976; Sternberg & Gardner, 1983), problem solving (Chi & Glaser, 1985; Greeno, 1974, 1976, 1978; Hayes, 1978), memory models and knowledge representation (Craik & Lockhart, 1972; Atkinson & Shiffrin, 1968; Norman & Rumelhart, 1975; Minsky, 1974; Pressley, Borkowski, & O'Sullivan, 1985), and learning (Biggs & Rihn, 1984; Chipman & Segal, 1985; Sheckels, 1983).

2.2 CHANGE AND LEARNING

Traditional approaches to assessing individual differences view man's psychological makeup as essentially static. In fact, they depend on stability and lack of change in order to be effective. In both the cognitive domain (where "ability" is the main concept) and in the personality domain (where "trait" is the equivalent concept) it is assumed that the individual being assessed has reached a stage of relative invariance. Abilities and traits are seen as compact summaries of the individual which can be used to predict performance on a number of real-life activities.

In some applications, this is a useful approach to adopt. In selection and placement exercises, for instance, the following information may be collected: The psychological demands of the job; the performance of the candidate on relevant ability and personality dimensions; and the "track record" of the individual -- has he successfully done similar jobs in the past? Underlying this approach is the assumption that the development of the individual is tending towards an asymtote on the dimensions in question. If the individual exceeds required minimum levels or falls within the acceptable range on the dimensions on which he has been assessed, then he is considered to have "what it takes" to do the job in question. Decisions made on this basis may be quite accurate if the candidate has a career history in the job category under consideration and if the job content is well defined and likely to remain stable over time. If these two requirements are not met, the probability of error is likely to be greater.

In a country such as South Africa with its diversity of cultural backgrounds and its widely varying quality of education, the asymtotic assumption is unwarranted in many instances (see the discussion in the previous chapter). In an advanced Western country with a standardized educational system, it is to be expected that an ability which is exercised in the school curriculum (such as reading comprehension) would be near its asymtote in young adults. Everyone would have had a fair chance to develop this ability by the time they reach young adulthood. The score on a test of reading comprehension is therefore a useful one for ordering people and predicting performance on tasks which require this ability. In a partially third-world country like South Africa, however, the standard of education, particularly between black and white, varies widely, as does the opportunity to acquire books and other reading material (due to financial constraints). Consequently, it is not justifiable to apply the reading comprehension test to all young adults and interpret the results under the asymtotic assumption.

An alternative approach is required. One of the most promising concentrates on the change variable of learning potential. Fortunately there is a growing recognition internationally of the value of measuring development capacity or learning potential. Much of the work is based on Vygotsky's (1978) concept of "zone of proximal development" which will be discussed in the next chapter. The work of Feuerstein, in particular, owes a great debt to Vygotsky (Feuerstein, 1980; Feuerstein, Hoffman, Jensen, & Rand, 1985). Schochet (1986) has applied Feuersteinian principles in his study of disadvantagement and performance at a South African university.

Learning theorists appear to be increasingly aware of the need to develop dynamic models of knowledge acquisition, especially where such knowledge is meaningful and highly structured (see for instance Estes, 1982; Reigluth, 1983). The era of studying the acquisition of meaningless material is passing away. Promising areas of research at present include: Knowledge representation and how this changes with experience (Glaser, 1984; Shavelson & Stanton, 1975; Stevens, Collins, & Goldin, 1982); strategies used in encoding information (Pellegrino & Ingram, 1979); and transfer of training, skills, strategies, etc. to new applications (Campione, Brown, Ferrara, Jones, & Steinberg, 1985; Campione, Brown, & Bryant, 1985; Hunt & Pellegrino, 1984). Several of these researchers have related conventional intelligence measures to elements of learning performance.

Psychology is likely to place stronger emphasis in the future on the theory and measurement of change. Models incorporating dynamic elements are inherently more sophisticated than static ones and require a more developed theoretical base; compare for instance Democritus's static model of the atom with the dynamic one of quantum physics. As psychology evolves more sophisticated theory, it will move to more dynamic models of man. The static models which are currently used in psychometrics have reached a point of maturity: significant improvements over the present level are not likely. In terms of predictive power, conventional tests seldom share more than about 16% of their variance with criteria (which corresponds to a correlation of 0,4). Refinements in these tests (to achieve higher reliability, greater factorial purity, or whatever) will not improve this performance appreciably. It is necessary to look to other approaches, possibly ones incorporating dynamic or change elements, in order to improve on this level.

The information processing trend mentioned in the previous section is not separate from the trends mentioned in this section. Much of the research done into change and learning is within the paradigm of information processing. The two are quite compatible, for the components and metacomponents used in information processing theory (see section 3.1) are often suitable vehicles to study strategies used in learning, representing knowledge, and transferring skills or "programs" to new applications.

2.3 INSTRUCTION AND DIAGNOSIS

Developments in education have been fairly heavily dependent on prevailing conceptions of the nature of intelligence. According to Snow and Yalow (1982) general and special abilities were, up to the 1960's, regarded as fairly fixed stable characteristics of persons. Differential development was thought to be predetermined by heredity, and efforts to enhance abilities were thought to be fruitless. The shock of the Russian successes in space and pressures from the Civil Rights movement led to educational reform in America aimed at developing intelligence, problem solving skills, and flexibility in cognitive functioning. The teaching of "facts" was no longer seen as useful because these swiftly become out of date in a world which is rapidly changing technologically and scientifically. Programmes such as Head Start, Upward Bound, and Sesame Street which frankly aimed at developing intelligence, were initiated.

Evaluation in the 1970's of these programmes was mixed but generally disappointing, especially with regard to the long-term benefits of the interventions. More recent analyses, however, have been more positive. It was realized that the wrong criteria of success were being used (such as improvements in IQ scores). When evaluated on other criteria, such as school grade attained for a given age and certain quality of life variables, the programmes seemed to have had a significant positive effect on those who participated (Zigler & Berman, 1983). The shortcomings of the programmes were mainly due to the shallowness of their impact on the lives of the participants. It was increasingly recognized that the family and community must be involved in order to secure major and long-term improvements.

The mainstream opinion about education and ability in the 1980's is that intelligence is, to a large extent, a product of formal education and informal influences by care-givers and peers. There is a greater recognition of the individuality of the student; as a result of this, ways are being sought to accommodate this individuality and adapt to it in the teaching situation in order to maximize the benefits of education to the individual. According to Glaser (1977, 1984), the fundamental educational task is to design settings for education that are flexible and adaptive enough to handle differences which derive from an individual's cultural milieu and his or her own uniqueness.

He claims that an educational environment which is not capable of adjusting to individuals inhibits the development of individual potential, becomes elitist, is heavily biased towards the mainstream culture, and perpetuates inequality. According to Glaser, educational institutions can no longer afford a "take it or leave it" approach to education. Education of this type is designed to benefit only a certain sector of the population. Because individuals in this sector receive education which is best suited to them, they excel; this perpetuates a myth that they are "the best" and hence the most deserving of places in educational institutions which prepare their students for high status careers.

From a cross-cultural perspective, Scribner and Cole (1973, 1981) also stress the need to take account of differences in individuals' approaches to cognitive and learning tasks. Learning occurs "out of context" in formal education. Children and adults not schooled formally may refuse to accept the system of assumptions embodied in out-of-context tasks (e.g., syllogisms with nonsense premises). Much use is made of abstract symbol systems in formal education. "Learning to learn", (what Scribner & Cole call "deutero-learning") develops from experience with these symbol systems. Consequently, individuals who have not been schooled formally may have difficulty in transferring learning, a process which formal education demands of students, and assumes that they can do. Scribner and Cole (1973) believe that the failure to analyze material into component parts may play a role in transfer difficulties. These issues should be taken into account when designing educational material and intervention procedures.

Adaptation can come from one of two sources: The educational institution or the individual. Traditionally, the onus was on the individual to adapt to the type of education given by the institution. As can be seen from the comments above, this situation is changing, and the onus is shifting to the educational institution to adapt to the individual. However, there are situations where adaptation of instructional material will not achieve the desired educational goals. There may be genuine lacunae in the individual's cognitive skills which cannot be circumvented by adopting a different instructional method. Some of the examples mentioned by Scribner and Cole (1973), probably fall into this category, such as the failure to analyze complex stimuli adequately or inability to reason with hypothetical (context-free) material.

There is a limit on the amount of adaptation one can expect from educational institutions, due to practical difficulties in adapting education to suit every individual's needs (Chipman & Segal, 1985). This difficulty is not likely to be totally removed even if education becomes heavily computer-based: Although instructional material can be adapted under program control, it is unlikely that models will ever be evolved which are infinitely flexible. Hence, some form of adaptation by the student will continue to be necessary. The most sensible model for education of the future appears to be one where adaptation is required by both learner and educational institution, and where the educational institution provides remedial procedures to assist the individual to adapt.

Despite the strong interest shown by many educational psychologists in the concept of adaptive education, well-developed theoretical models are at present lacking; the only adaptive aspect that has been implemented on any scale is rate of instruction (especially in computer-aided instruction). Cognitive instructional psychology is, however, emerging as a major topic of research. Snow and Yalow (1982) comment on the work done in this area: "The research seeks to understand in detail how individuals, and thus how different individuals, function psychologically to perform the kinds of tasks taken as indicators of intelligence, of learning from instruction, and of outcome from instruction" (p. 497). The projected research has at least two aims: to develop ways of optimizing the benefit of education to the widest spectrum of people, and to study the interrelationships between instruction, learning, and intelligence.

The agenda which is outlined by Snow and Yalow (1982) can only be undertaken if a process approach is adopted. There are many sources of individual differences in information processing (see section 3.1). In an educational context, these differences can be interpreted meaningfully only if the precise nature of the learning task is understood (see Baker and Herman, 1983). The importance of paying attention to the design and nature of learning tasks has been known for a long time. Bloom (1956) and Gagne (1970) both make mention of it. Only recently, however, has it been realized that learning and instruction should be analyzed in cognitive process terms, an approach which the earlier researchers did not adopt. Snow (1979a) and Snow and Lohman (1984) describe some of the prerequisites of a process-based theory of aptitude for learning.

At this stage, most research into individual differences in learning concentrates on phenomena which are at a fairly gross level. Pask (1976) and Thorndyke and Hayes-Roth (1979) for instance, identify two types of learners: Serialists and holists. Doyle and Rutherford (1984) mention a total of four learning styles. Cognitive or learning style is considered an important area of study because styles cut across traditional ability domains (Frederico, 1981).

Similarly, those who have studied instructional methods have tended to investigate rather gross characteristics of instruction. Cronbach and Snow (1977) undertook a massive survey of research on interactions between aptitude and instructional methods. One of their criticisms of these aptitude-instruction studies is that very coarse-grained assessments of ability or aptitude are used. This line of research is not likely to yield useful results unless more attention is paid to applying process concepts both to the instructional material and to the procedures used by the individual to cognize and master the material.

What is the role of assessment instruments in these developments which are occurring at the interface between cognitive psychology and education? Baker and Herman (1983) say that there is a need for greater contact between those with expertise in learning and instruction on the one hand, and those with psychometric skills on the other. Although this statement is undoubtedly true, it does not go far enough. It is necessary that the testing and educational fraternities develop a common language of discourse, so that a greater integration of cognitive research, testing and education can take place; the products of testing should be able to feed into education and the products of education should be able to feed into testing. Both of these should enrich and be enriched by cognitive psychology. This can only happen if both disciplines use similar concepts. These concepts are likely to be of a process nature, possibly with an emphasis on metacognitive constructs.

The purpose of testing and the nature of tests is likely to change radically in this context. These issues will be discussed in greater detail in later chapters. We shall at this point only mention them briefly. At present tests benefit mainly the user rather than the testee. This is true in both the educational and industrial spheres. Also, the benefits which may accrue to testees (such as job appointments or acceptance into educational institutions) may be unfairly apportioned due to test bias and other factors (see the references to Glaser 1977, 1984, above). The new form of testing discussed here holds equal benefits for test users and testees: The test user obtains more accurate information on testee's cognitive makeup and can adapt the work or training to capitalize on the testee's strengths or preferred styles of operation. Where adaptation is not possible ("adaptive job content" is still rather a novel idea), lacunae found in the testee's cognitive armoury can be filled through specially adapted training inputs.

This type of procedure is only possible if diagnostic tests are devised (see Kail and Pellegrino, 1985, for further discussion on the need to take the diagnostic route in test construction). Diagnostic tests which have been devised to date have unfortunately acquired rather a negative image because they have been designed to pinpoint deficiencies in very limited domains (in adding numbers, for instance). What is needed are diagnostic instruments based on process or metaprocess concepts. Not only would such tests be of great practical use; they would also form a bridge between cognitive research and education. Bejar (1984) identifies three psychometric approaches to diagnosis: Identification of deficits, error analysis, and a cognitive processes-artificial intelligence approach. The last-mentioned is at present in its infancy. Bejar believes that the cognitive-artificial intelligence approach will enrich and integrate the field of diagnostic assessment. This approach will also make it possible to assess knowledge representation, an area which the present author feels is of prime importance in diagnostic testing.

One of the most ardent proponents of a diagnostic approach to assessment is Feuerstein (see Feuerstein, 1980; Feuerstein, Hoffman, Jensen, & Rand, 1985). Although Feuerstein's approach is somewhat individualistic, he has to an extent incorporated process variables into his theory. Feuerstein makes use of assessment instruments, but in an informal, unstandardized fashion; his approach is largely clinical involves informal, non-standardized interaction between psychologist and subject during assessment. Although diagnosis under these conditions can be done effectively, this approach is not rigorously qualitative and requires a large investment of skilled time. As in psychotherapy, the quality of the results is largely dependent on the skill of the psychologist. Little or no effort has been invested by Feuerstein and his colleagues into building diagnostic capability into the measuring instruments themselves.

Several authors see learning potential, or modifiability, as an important concept in diagnosis. This concept can be traced back to the work of Vygotsky (English translation: Vygotsky, 1978), who coined the term "zone of proximal development". Feuerstein's diagnostic procedures rely heavily on a "Learning Potential Assessment Device" (LPAD). Bejar (1984) believes that degree of modifiability gives an indication of the likelihood of success of remediation of deficits. Snow (1979a) points out that despite the importance attached to learning potential, conventional tests do not measure this characteristic directly. Some tests, such as the Raven Progressive Matrices include learning as a component, but a score on the amount of learning which takes place during testing is not available. According to Snow, a test which measures learning potential would indicate the subject's capacity to adapt his strategies through new assemblies of processes. Prior knowledge of both a declarative and procedural nature can act as a scaffolding on which new cognitive structures are built (Di Sessa, 1982; Reigeluth, 1983). A long-term aim of modifiability assessment should be to measure these changes in structure with experience or training.

2.4 PROBLEM SOLVING

Strictly speaking, most tasks required of subjects in testing and experimental contexts are problem solving tasks. In practice, however, only those tasks which have most of the following characteristics are usually referred to as problem solving exercises:

1. Multiple steps are required to solve the problem;
2. There is a well defined starting point and goal point;
3. There is a clear set of rules or legal "moves" which defines the "problem space";
4. There is a surface "story" of some sort;
5. An "off the shelf" set of steps to do the task is initially not available to the subject.

Problems may not have all the above characteristics. For instance, not all problems have a clearly defined goal state: The subject may have to find this for himself. In some problems, such as Duncker's (1945) classic problems, the goal state is clearly defined, but the "rules of the game" are vague. However, the problems that are most useful from the point of view of psychological research tend to have all the above-mentioned characteristics.

Problem solving is attracting an increasing amount of research because it is a nexus which links several other branches of research. Newell and Simon's (1972) work probably contributed, more than any other research, to establishing problem solving as a central research area in psychology. Earlier work on problem solving such as Duncker's (1945) and Luchins' (1954), although of interest especially with regard to cognitive flexibility, was of relatively peripheral importance. Newell and Simon's approach, which is based on the computer metaphor, succeeded in giving researchers a way of analyzing the details or specific steps which might go into the solution of a problem. These explicit steps (production systems) are analogous to statements in a computer program. The authors were able to operationalize problem solving processes to the point that they could develop a program (the General Problem Solver - GPS) to solve certain types of logical problems.

The GPS was based on a very mechanistic model and employed problem solving procedures which are probably seldom used by humans, especially when they are doing problems in a content areas with which they are familiar. Nevertheless, Newell and Simon's (1972) work helped to establish the foundations for later information processing theory (such as that of Sternberg, 1977, and Caroll, 1976) and to establish problem solving as a powerful research vehicle to study many important issues in cognitive psychology.

We may illustrate the above point by listing some of the areas of cognitive psychology in which problem solving has been used as a research vehicle: Intelligence (Polson & Jeffries,1985; Resnick & Glaser, 1976; Sternberg, 1982); memory (Greeno, 1973); knowledge structure and representation (Chi, 1981; Chi & Glaser, 1985; Hayes, 1978); Kotovsky, 1985; Voss, 1979); learning (Egan & Greeno, 1974; Pellegrino & Ingram, 1979); induction (Pellegrino, 1985; Sternberg, 1982); information processing (Simon and Simon, 1978; Greeno, 1976; Hayes, 1978); artificial intelligence (Minsky, 1974; Newell & Simon, 1972; Richardson, 1983).

Problem solving tasks can be used effectively to study the more dynamic aspects of cognition (see section 2.2), as the subject has to perform a number of transformations on the data of the problem in order to achieve a target goal. Concept formation (as in classificatory tasks) and perception of relationships (as in analogies tasks) are frequently studied and measured, but the more dynamic behaviour of making transformations is seldom studied or measured in its own right, despite the fact that most tasks require individuals to transform data. de Riencourt (1980) says that the idea of transformation is introduced into Western scientific models only with difficulty because in the West there is a penchant for analyzing "dead" and static systems. Life and dynamism are often killed on the dissecting table of Western science in the quest for "information," as opposed to "transformation". Clearly, if psychology is to learn more about the dynamics of thought processes, more dynamic concepts, like transformation, will have to be introduced into its research models.

Problem solving tasks can also be used to study stylistic or strategic differences in going about a given task. Styles or strategies reflect the overall management of the problem solving process and give clues as to the type of metacomponential control being applied (see section 3.1). It is important to gain information on metacomponents because this knowledge can be useful in diagnostic and remedial applications.

In the opinion of the author, problem solving tasks probably give the most useful information when integrated with a didactic programme. This has been done informally for years by teachers: tests and examinations (incorporating problems) are used to assess what has been learned. Procedures of this kind tell a cognitive theorist little or nothing, however. What is needed is to develop material specifically designed to study processes, strategies, and knowledge structure at various points during a carefully designed educational process.

2.5 COMPUTERIZATION

Computers are being used increasingly in testing, experimental, and educational applications. Most of the benefits of computerization can be classified into one of the following two categories.

1. Efficiency. Computerization may allow a particular task to be done more quickly, accurately, or cost-effectively.

2. Capability. Certain types of task can be done successfully only if a computer is used.

The computer offers a number of advantages in testing. Some of these have been described by Taylor (1983, 1986). Possibly the most important of these are: the capacity to do adaptive testing, and the capacity to devise new types of measures. We shall define "new" types of measures as those which give information about subjects which could not be obtained using conventional ability and trait measures.

In adaptive testing, the testing program keeps track of the correctness of the subject's responses and uses this information in order to select items for presentation to the subject. A substantial body of theory for adaptive testing has been developed (see Samejima, 1977; Weiss, 1980). Adaptive testing theorists have been mainly concerned with improving conventional tests rather than measuring new aspects of cognitive functioning. Testing times are shorter in adaptive tests because fewer items are necessary for a given accuracy of measurement; hence, the benefits of adaptive testing fall mainly into category (1) above. The information about the subject which is obtained is much the same as would be obtained from a normal pencil-and-paper test. This situation may change in the future. Samejima (1983) has developed a model which is applicable to tasks which allow the subject a number of strategy paths.

A wide variety of new types of measures can be devised using the medium of the computer. Some of the earlier tests in this category made use of the capability of the computer to display, move and erase information under strict program control. Cory, Rimland, and Bryson (1977), for instance, devised a number of "information processing" tests, including movement detection, perceptual speed, short-term memory, closure, etc. Chiang and Atkinson (1976) devised a memory search measure. These, however, constitute a fairly prosaic use of the capability of the computer medium. A more ambitious use of the computer was undertaken by Johnson (1978) who studied individual differences in concept learning strategies of the Bruner type (Bruner, Goodnow, and Austin, 1957). Johnson cleverly programmed his material so that "lucky guesses" were eliminated. The target concept was not selected in advance; instead it was assigned, after each question asked by the subject, to a domain of the stimulus material which had not yet been explored. The identity of the concepts became fixed only after all uncertainty had been eliminated by the subject. Hence the number of steps required to achieve a solution was maximized and a greater sample of the individual's strategic behaviour was obtained.

As can be seen from Johnson's (1978) technique for assessing how an individual goes about forming Bruner-type concepts, computerized instruments can be devised which offer the subject a multiplicity of possible response paths and it is therefore possible to gain information on the styles and strategies used by the subject to do the task. Some of the more recently programmed NIPR computerized tests give information of this kind, for instance the "maze" test which assesses the individual's handling of large quantities of information (Tredoux, 1985). More work still needs to be done to develop adequate theoretical models for tests of this type, however.

Tasks such as those devised by Tredoux (1985) and Johnson (1978) are problem-solving exercises. A bright future seems to lie ahead for assessment instruments of this kind. Hunt and Pellegrino (1984) and Hunt (1982) state that a good case can be made for regarding the essence of intelligence as the ability to transfer problem-solving techniques learned in one situation to other analogous situations. A variety of interactive computerized testing procedures could be used to identify a person's style of problem-solving and determine the extent to which styles and strategies generalize over situations. Hunt and Pellegrino say that information obtained from such an exercise could be used to devise ways of "improving" the individual's style of problem-solving. Problem solving will be discussed in more detail in Section 2.4.

The computer can be used to achieve a number of important objectives in educational assessment. The most important of these are diagnosis and student modelling. Glaser (1977,1981) sees diagnostic tests being used as a necessary adjunct to what he calls adaptive education. Burton (1982) has devised a method of modelling simple arithmetic which is also capable of modelling student errors. These methods usually incorporate an artificial intelligence component, and hence can be administered only through the medium of the computer. Diagnosis and education will be discussed in more detail in Section 2.5.

Another area in which the computer has been used as a powerful tool is in experimental psychology, especially in the theoretical aspects of cognitive psychology. In information processing models, such as the componential models developed by Sternberg (1977, 1982), and Sternberg and Gardner (1983), it is necessary to measure response latency to a high level of accuracy. Sternberg identifies six components which are activated in order to solve analogies. The execution of some of these may take a very short time. Computerized administration of stimulus material is essential in order to investigate performance on multicomponent tasks.

2.6 SUMMARY

Developments currently taking place in cognitive psychology will have an impact on the nature and role of assessment and education. At the heart of these changes is a more person-centred psychology. Traditionally, cognitive psychology, psychometrics, and education have been nomothetically orientated. The comparability of humans with one another has been emphasized at the expense of their uniquenesses. This approach is unavoidable when only simple models are available; under these circumstances, generalizations have to be made.

With increasing theoretical sophistication, psychology can adopt a more idiographic approach. In cognitive psychology, the current ascendancy of information processing research indicates that theorists are asking new questions: Ones to do with quality rather than quantity. The interest is in how rather than how much. The shift to an idiographic position is still in its infancy, however. Even when studying "how" questions, cognitive psychologists often make the assumption that all humans go through the same processes, in the same order, when doing a given task. In order to actualize the idiographic approach fully, very flexible models will have to be created which allow for individuality in the styles and methods used by people in processing information.

The idiographic orientation in education will result in the creation of more learner-centred methods of instruction. The intention is to optimize the benefit of education to all, not just to a certain segment of learners. In order to achieve this aim, both adaptation of educational material and remediation will be necessary.

New types of assessment instruments will be needed to assess individual differences in the way people process information. Without instruments of this kind, it will not be possible to do the diagnostic assessments required to design adaptive or remedial inputs, and to monitor changes in processing skills and styles as a result of education.

Not all research into aspects of information processing can be done in an educational context, because of the large number of uncontrolled variables involved. Problem solving tasks should be designed to study information processing, learning, and knowledge or memory structures in a more controlled environment. Problem solving is a useful vehicle for the study of the dynamic aspects of cognition because a number of steps are usually required in order to solve a problem. The challenge to the test constructor is to devise problem solving material which makes it possible to externalize the processes used by the individual.

Computers are essential to the full realization of many of the developments mentioned above. "Products" can be studied adequately using conventional pencil-and-paper methods, because products can be simply written down after the processes have been executed. Processes, on the other hand, cannot be studied adequately using conventional methods. The capacity of the computer to continuously monitor and record all responses, adapt to the subject's responses, and make accurate time measurements, are essential for the application of sophisticated idiographic information processing models.

Cognitive psychology, educational psychology, and psychometrics should be brought together under an information processing umbrella. These disciplines can mutually enrich one another.

3.0 TOPICS OF SPECIAL INTEREST

In this chapter, topics which may be relevant to future developments in testing will be explored. These topics are more specific than the ones covered in the previous chapter, and the literature will be examined in more detail, especially with regard to theoretical issues which may be important in developing new assessment approaches.

As was the case in the previous chapter, the topics are not totally discrete. It is therefore unavoidable that a certain amount of overlapping will occur in discussion of the topics. This is not totally undesirable, as it facilitates the integration of the different topics.

3.1 PROCESSES AND METAPROCESSES

Introductory comments

Most cognitive tasks which people do in their daily lives or in psychological tests are of a "macro" nature. These tasks can be split into a number of smaller "micro" steps which have to be executed in the right sequence in order to complete the macro task successfully. Cognitive psychologists are becoming more aware, however, that more than one sequence of a given set of micro steps may result in the satisfactory completion of a macro task; also different selections of micro steps may appear in different peoples' procedures for doing the task, and different lengths of time may be devoted to individual micro tasks by different people.

These differences at the micro level may be unrelated to final success in completing the macro task, in the same way that two different computer programs may produce the same output but be composed of different lines of code. Certain gross characteristics of a sequence of micro steps may be discernible, and these may be referred to as "styles" of doing the macro task. Different styles may not be equally efficient in completing a task, however, especially when context is taken into account. A task may be regarded as satisfactorily done in one context but not in another. Examples of contextual factors which might have a bearing on the judged success of an individual's effort to do a task are: time constraints, accuracy, and the aim of the task. It may or may not be important to do the task within a restricted amount of time. There may be different standards for accurate productions in different contexts. Stated task requirements do not always include certain expectations imposed by the context; in a classificatory task, for instance, the testee may believe that functional classifications are required, whereas the experimenter expects the individual to produce classifications based on shared attributes.

From the above discussion it is clear that cross-cultural issues cannot be ignored in information processing research. Although certain specific processes may be used by individuals in all cultures (Verster, 1986) the choice and ordering of processes to achieve a macro task is likely to be influenced by cultural factors. This has implications for multicultural societies, where many individuals are continually crossing the cultural "divide", in the sense that they may be required to operate in a cultural context which is secondary to them. A sequence of processes which successfully completes a task in one's primary cultural context may not adequately complete an apparently similar task in a secondary context, due to different task requirements imposed by this context.

A caveat which should be observed by cognitive psychologists and the constructors of measurement instruments is not to fall into a trap of cultural chauvinism by assuming that there is only one "right way" to do a task. A psychologist may discover that all or most of the individuals in his culture who do a particular task successfully use a particular sequence of processes; this does not permit him to assume that this is the only way to do the task and that individuals from a different culture are somehow deficient if they do not use this sequence of cognitive steps. Assumptions of this type can lead to unfair practices in selection. Tests included in a selection battery may be inappropriate for certain individuals: It might be assumed, for example, that inductive reasoning is required to do a particular task, whereas certain individuals manage to do the task by using their memories. Berry (1984) describes the advantages of what he calls the cognitive styles approach in cross-cultural research. This approach assumes a position of cultural relativism: Skills and strategies may be culture-specific. The approach nevertheless addresses itself to finding systematic relationships among abilities doing cross-cultural comparisons. In the educational domain, Glaser (1977, 1981) points out that instruction should as much as possible, adapt to the cognitive routines which the individual has already acquired, rather than forcing him to adopt a different approach. Obviously there will be cases where an individual who is moving into a different cultural milieu will have lacunae in his armoury of procedures, but remedial interventions should only be undertaken if it appears that the individual has no way which can be used or adapted to do the task.

Most of the research into cognitive processes has been done in the experimental, rather than individual differences, domain. By ignoring individual differences, however, researchers may obtain results which are "messy" and uninterpretable. In a study reported in Hunt (1980), for instance, it was found that one information processing model fitted the data rather poorly; much better fits to the data were obtained when different models were used for "spatial" and "verbal" information processors. Sternberg and Gardner (1983), conducted a study in which different types of reasoning tasks (classification, series, and analogies) were presented in verbal, schematic, and geometrical forms. They found that some of their processing components (inference, mapping, and application) had to be combined into a single construct (reasoning) in order to increase reliability. This slightly comical situation, in which a processing theorist is forced to use a macro construct like reasoning, probably resulted because individual differences (in order and choice of processes) were not taken into account.

Information processing theories

Newell and Simon's (1972) book heralded a new era of cognitive psychology which was concerned with processing concepts rather than "black box" explanations. These authors made the following claims for their new theory:

1. It moves closer than previous theories to a description of the individual rather than of statistically defined populations (it is hence more idiographic, less nomothetic).

2. It is content orientated: It attempts to account for specific human activities, such as playing chess, doing cryptoarithmetic, etc.

3. It is dynamically orientated: It describes changes in the states of systems over time.

4. It emphasizes the concept of sufficiency: A premium is placed on discovering systems of mechanisms that are sufficient to perform the cognitive task under consideration.

Newell and Simon's (1972) theory is heavily based on the computer metaphor. They define an information processing system in terms of seven requirements which are very mechanistically phrased. An information process, for instance is defined as a process that has symbol structures for some of its inputs or outputs. An important concept which Newell and Simon introduced, and which has been taken up by other theorists, is that of the production system (see also Newell, 1973). Production systems are compilations of conditional statements: The "if-then" statements of propositional logic and computer programs. A "program" to execute a given task consists of a number of production systems linked in a specific order. The "richness" of programs composed of production systems lies in their ability to respond to a number of states of their environment. At each step the state of the data on which the program is working is tested and the program branches accordingly. Consequently there are myriad paths through the program. The adaptability of human behaviour is captured to a certain degree by this type of system.

Newell and Simon (1972) used their theory to construct the program, known as the General Problem Solver (GPS) to solve problems of a logical-symbolic nature (see section 2.1). As their theory is so closely allied to computer science, this task was easier than it would otherwise have been. The authors optimistically thought that the GPS or some derivative could "pull itself up by its bootstraps": Learn through experience and become an ever more powerful problem solving machine. Subsequent research in Artificial Intelligence has shown that the problem of creating machines which can develop cognitively is much larger than Newell and Simon envisaged. Part of the difficulty lies in giving the machine effective ways of representing information, changing these representations in the light of new data, and incorporating contextual information (see Dreyfus, 1979, and Dreyfus & Dreyfus, 1986). All successful problem solving programs developed to date operate in a very limited context.

Newell and Simon's (1972) ideas have been developed by a number of theorists, notably Carroll (1976), Brown (1978), and Sternberg (1977, 1982, 1985b).

Carroll (1976) borrows the production system concept from Newell and Simon (1972). According to Carroll, the various condition-action statements incorporated in a production system specify not only the task itself, but also the rules and strategies by which the subject performs the task. Individual differences in subjects' production systems fall into three categories: Differences in the composition and ordering of sets of condition-action rules; differences in the temporal parameters associated with these condition-action rules (e.g., the length of time spent on a given if-then decision); and differences in individuals' success in applying their productions systems. A number of factors can influence success in applying production systems. Differences in the contents of permanent memory, for instance, can determine whether a problem can be solved (the problem may for instance depend on the knowledge of a particular word).

Taking French's Kit of References Tests as his universe, Carroll (1976) divided task characteristics into six categories. Some characteristics refer to "external" phenomena (e.g., type of task presented), and some refer to "internal" phenomena (e.g., the types of operations and strategies that would probably be employed in a central processor). Typical operations and strategies identified by Carroll are: recognize, educe identities, store in memory, judge a stimulus with respect to specific characteristics, mentally rotate, ignore irrelevancies, rehearse, chunk, construct a hypothesis, do a memory search, represent abstractly. Carroll distinguishes between operations and strategies. Operations are control processes which are specifically specified or implied in the task instructions, while strategies are control processes which are not specified but which may be "discovered" by the subject. The interaction of instructions with the task performance is as much central to control as the internal part of the performance program. For this reason, Carroll believes that a fully-fledged theory of instruction is required.

Brown and his colleagues made an important contribution to information processing theory by distinguishing two types of processes: Metacognitive and cognitive processes (Brown, 1978; Brown & Ferrara, 1985; Campione, Brown, & Bryant, 1985; Campione, Brown, Ferrara, Jones, & Steinberg, 1985). Metacognitive processes are executive or control activities which are necessary for the successful and efficient completion of tasks or solution of problems. Five classes of metacognitive process are distinguished by these authors: Planning (the steps to be used to do the task), monitoring (the effectiveness of the steps taken), testing (one's strategy as one performs it), revising (the strategy as the need arises), and evaluating (the strategy for effectiveness). Processes, on the other hand, are non-executive mental acts required to implement task strategies. Processes such as encoding, comparing, rehearsing, etc. fall into this category.

We shall come across the work of these authors in other sections in this chapter. One of the strong points of their theory is that it builds bridges, through the use of the metaprocess concept, between a number of topics of interest in this report, including memory, transfer, strategies, and learning potential.

Sternberg (1977) distinguishes three approaches to the study of cognitive functioning. These are the factor analytic approach, the information processing approach, and his own approach which he calls the componential approach. Sternberg criticizes the factor analytic approach on a number of counts: An infinity of solutions are mathematically possible; factor analysis deals only with the end-point of human thinking; the type of analysis which can be done is of an intraindividual rather than an interindividual nature.

Sternberg (1977) is also critical of the pure information processing approach. The scientific desideratum of parsimony has not been achieved: The information processing approach has not produced any comprehensive theories of intelligence, only theories of tasks. There may be no way of determining the order in which processes are executed. Individual differences are often ignored by positing a single model which is supposed to be appropriate for all. Sternberg himself is not free of criticism in this regard (see the comments, above, on the study of Sternberg and Gardner, 1983).

The third approach, the componential approach, is according to Sternberg (1977) an attempt to unite the strengths of the other two approaches. His aim is to retain the capability of the factor analytic approach to discover constellations of mental operations through the use of powerful psychometric techniques, while simultaneously retaining the capability of the information processing approach to "get inside" composite tasks and discover what mental operations are necessary to produce the final output. In order to address the problem of non-transferability of basic processes from one task to another, Sternberg proposes not to include processes at the most "micro" level, and to combine these into larger processes or components. Factors are not to be regarded as latent traits, but as constellations of components that in combination form stable patterns of individual differences. By nature both tasks and factors are arbitrary. The number of tasks that can be devised requiring different combinations of components is endless. Components, on the other hand, are not arbitrary and their number is finite.

Sternberg (1977) illustrates his theory by describing analogical reasoning which he claims involves six processing components (see also Sternberg and Rifkin, 1979). Sternberg subsequently extended this approach to the whole domain of reasoning (see Sternberg, 1979, 1986b; Sternberg and Gardner, 1983).

Despite Sternberg's (1977) claim that his theory is based on larger, more transferable basic elements, his components appear to be little different in terms of "size" from those of other information processing theorists. In his later work, Sternberg, has started placing greater emphasis on metacognitive units. Sternberg (1985b) distinguishes three types of processing components. The first type, metacomponents, are comparable with Brown's (1978, 1986) metacognitive processes. Ten of these are identified (e.g., recognition that a problem exists; selection of a set of lower-order components to perform a task; selection of a representation of information; decision on how to allocate attentional resources). The second class of components, performance components, are lower-order processes used in the execution of various aspects of a task (e.g., encoding the nature of a stimulus; inferring the relation between two stimulus terms that are similar in some way; applying a previously inferred relation to a new situation). The third class of components includes knowledge acquisition components, which are processes involved in learning new information and storing it in memory (e.g., selective encoding of new information on some criterion of relevance; selective combination of encoded information with already stored information in order to maximize the interconnectedness of the new information with the old).

Sternberg (1985) proposes six sources of individual differences in information processing:

1. Individuals may use more, less, or different components to do a particular task.

2. Some individuals may combine components according to one rule, some according to another rule.

3. The components may be activated in different orders.

4. People differ in the mode of component processing. For instance, a memory search may terminate as soon as a piece of information is found, or the search may not terminate until all available material has been examined.

5. People differ in the time taken on each component and the accuracy with which it is executed.

6. Some people may represent information in one way (e.g., pictorially) while others represent the same information another way (e.g., verbally).

It should be clear from this list why information processing theory has had problems generating broad theories. It is one matter to itemize the sources of individual difference, but quite another to incorporate all these features in a general model of information processing. For this reason, most research concentrates on very circumscribed tasks where many of the above sources of individual differences are either absent or controlled.

The recent interest in metacognition has helped combat the uncontrolled proliferation of process elements, many of which are accepted and used by only one theorist in order to describe a particular task. Different theorists also have different sets of metaprocesses, but at least the universe of these processes is likely to be smaller than the universe of first-order processes. Metaprocesses are likely to have greater generality across tasks. They are also important in that they reflect strategic differences which could be of interest in diagnostic assessment.

A number of information theorists have tried to relate concepts in their theories to traditional views of intelligence. Sternberg (1982) believes that reasoning and intelligence are so closely related that it is difficult to tell them apart. Traditional definitions of intelligence such as Spearman's (1927) (intelligence is the eduction of relations and correlates) are reasoning definitions, grossly stated without reference to processing concepts.

According to Sternberg (1982), "Reasoning may be characterized as an attempt to combine elements of old information to form new information" (p. 235). Much of his theoretical work is concerned with describing how this happens componentially in various types of inductive tasks (analogies, classifications, series completions, causal inference, matrix problems) and deductive tasks (syllogisms, propositional logic). All these types of task are common in tests of intellectual ability. Sternberg emphasizes the importance of being clear about the componential content of test items; tests should be constructed which contain a known set of cognitive processing tasks. Certain components or metacomponents could be singled out for special attention. The metacomponent of planning is a case in point. Successful problem solvers spend more time planning their strategies and less time executing performance components than unsuccessful problem solvers (Sternberg, 1985a). Kirby (1984a) points out that most commonly used intelligence tests are not designed to test planning; he believes that because of this there is a gap in the domains covered by conventional tests.

The approach of the authors discussed in the previous few paragraphs is called the cognitive components approach. This should be contrasted with a different approach, which Pellegrino and Glaser (1979) call the cognitive correlates approach. In this approach, the aim is to identify those information processes that are differentially related to high and low levels of aptitude or intelligence (see Cooper & Regan, 1982). Pellegrino and Glaser give examples of the types of questions which the two approaches attempt to answer:

Cognitive components: "What do intelligence tests test?"

Cognitive correlates: "What does it mean to be high verbal?"

Hunt and his associates are probably the most important exponents of the cognitive correlates approach. Hunt, Frost, and Lunneborg (1973) point out that most psychological tests inherit from Binet's time the undesirable characteristic of being almost atheoretically based. The "bottom line" is prediction, not a theory of cognition. These authors believe that the cognitive correlates approach can help overcome these shortcomings of psychometric tests. The research has been set in the context of a computer-inspired model of memory. The authors believe that, through the use of analysis and simulation, it should be possible to find those parameters and "programs" which are most crucial in determining individual differences in intellectual performance. Tests could then be devised to measure directly the parameters or programs used. These tests would, collectively, be a theoretically based measure of intelligence.

Studies in which differences on certain model parameters were found between high and low verbals and high and low numericals are reported in Hunt et al. (1973) and Hunt and Lansman (1975). For instance, loss of information from intermediate term memory was reliably lower for subjects in the high quantitative (vs. low quantitative) group.

In his later work, Hunt has emphasized a concept which he calls strategy, a high level co-ordinating process. Hunt (1980) notes that information processing tests seldom correlate strongly with conventional tests of cognitive ability. The reason for this is that information processing tests are "strategy-poor" whereas conventional tests are "strategy-rich", although these tests are not designed to measure strategies directly (Hunt, 1982). Strategies are high-level controlling, co-ordinating, and planning processes. They are essentially a method of approaching a task and using the resources of the processor optimally (Kirby, 1984a, 1984b). Typical information processing tests present people with very restricted problem solving situations in which there is only one reasonable way to do the task. Reasoning and comprehension tasks, on the other hand, may be tackled in a number of ways. Even in relatively simple tasks like comparing a pictorial representation of two symbols with a verbal statement about these symbols people differ in their solution strategies. Intelligence may be seen as the "ability" to make good strategy choices. Cognitive behaviour is a compendium of structural capacities and strategies to hold them together.

Some of the work of Snow is compatible with Hunt's theoretical orientation (Snow, 1979a, 1981; Snow and Lohman, 1984). Snow constructed a space of mental tests using a multidimensional scaling technique related to the Guttman radex. This space has three sectors, two of which correspond to Cattell's (1971) fluid and crystallized intelligence; the third is a visualization sector. "Simple" tests were found to be located at the periphery of this space and the "complex" ones at the centre. The tests located at the centre were of the type typically used to measure crystallized and fluid ability and spatial vizualization; tests at the periphery were more akin to the tests typically used to measure various aspects of information processing (e.g., repeating digits backwards and forwards). The tests at the periphery also tended to be more speeded and had less item variability. Tests at the centre of the space on the other hand required the subject to select and adapt strategies to do each item.

Snow (1981) and Snow and Lohman (1984) state that there are at least two prerequisites for intelligent behaviour: The possession of many different "off the shelf" programs to do a variety of tasks (this corresponds to crystallized intelligence), and the ability to reassemble or modify programs in order to be able to do unexpected or novel tasks (this corresponds to fluid intelligence). Complex tasks involve more involvement of assembly and control processes. Both structure and malleability is therefore required of the performance programs used by humans to do a wide variety of tasks which confront them in their daily lives. Snow and Lohman state that componential analysis makes an important contribution to theory construction, but the individual components thus identified seem to lie beneath the level of construct that has most utility for explaining complex tasks. Componential analysis often ignores dynamic adaptations which are the main causal links between aptitude and complex learning. It is here that control and strategic concepts can be powerful tools in explaining cognitive behaviour. Although Snow and Lohman do not say how these concepts relate to metacomponents, it is probably safe to say that they are high-level metacomponents.

The present author agrees that cognitive research can be most fruitfully conducted using constructs of this magnitude. To illustrate this, let us draw an analogy with concepts in microbiology. We shall say that components are analogous to molecules and production systems to strings of chemical reactions which happen in the cell. Although these phenomena are of interest as basic structures and processes in the cell, higher-level phenomena are often more descriptive of the overall functioning of the cell. These higher-level phenomena (like control functions exercised by segments of the DNA, and microstructures in the cell such as ribosomes and mitochondria) correspond to higher-level metacomponents and strategies.

Both the schools of information processing research reviewed above (cognitive components and cognitive correlates) see a place for conventional intelligence type tests in their research. Some theorists, however would rather throw the traditional intelligence concept overboard as a relic from an era which was complacent about theoretical issues. For them, the definition of intelligence is inescapably circular ("intelligence is what intelligence tests measure"). There is little point, according to this view, in concerning oneself with the relationship between information processing variables and tasks which appear in intelligence tests; a more worthwhile approach is to apply the concepts of information processing to real-life tasks, such as the tasks required of children in the schoolroom, or tasks which are regarded as important within a particular cultural context. Berry (1974, 1984), and the Laboratory of Comparative Cognition (1982) appear to endorse this approach. Sternberg himself seems to have become more accepting of it in his later publications. Sternberg (1984b, 1986) espouses the necessity of adopting a contextual approach in order to escape the circularity of intelligence definitions: Tests should be evaluated against real-world intelligent behaviours. This view is also inherent in Sternberg's triarchic theory of intelligence (Sternberg, 1984a).

Snow and Peterson (1985) regard the approach of concentrating on real-life cognitive performances as a third approach on a par with the cognitive correlates and cognitive components approach. They refer to it as the cognitive contents approach. Snow and Peterson believe that cognitive contents research will lead to models of achievement that will help to explain the differences between more and less able learners. This work should lead in turn to diagnostic process tests of differences in knowledge organization and to models of declarative and procedural knowledge acquisition. A start in this direction has been made by Egan and Greeno (1973) who combined the following factors in a single study: Different modes of instruction, different levels of cognitive competence, and a faceted post-test of learning and transfer. In the post-test, two vehicles of presentation (words and formulae) were crossed with three levels of learning transfer (low, medium, and high) to produce six kinds of task. The approach of creating faceted measurement instruments to assess performance after a particular type of instructional input may ultimately lead to the development of powerful diagnostic instruments and to a greater understanding (in process terms) of the relationships among instruction, learning and cognitive performance.

Faceting involves generating a content space defined by a number of independent dimensions. Points are indentified on each dimension (e.g., level of transfer in the above example). The points on the dimensions are "crossed" with one another to produce items which fall in the space defined by the dimensions (Guttman, 1965). The faceting of achievement tests must be designed in such a way as to learn as much as possible about the individual's processing of information on different types of task. The cognitive contents model should be designed to include repeated measures, so that learning curves over blocks of items can be obtained. Inserted into this sequence may be training treatments designed to alter component skills or executive strategies.

Very little research has been done on information processing in a learning or instructional context. One of the few information processing studies which incorporated an instructional component was conducted by Sternberg and Weil (1980). In this study, subjects were instructed to do syllogisms in different ways -- using spatial, linguistic, algorithmic, and mixed strategies. Performance on the syllogisms was related to spatial and verbal abilities. The study was therefore a "hybrid" in that it incorporated both traditional ability measures and more fine-grained process variables. Also, performance was not assessed repeatedly during the learning process.

The Sternberg and Weil (1980) study clearly has elements of the aptitude-treatment-interaction (ATI) model (see section 3.4 for a discussion of this model). In its normal form, the ATI model incorporates only gross measures of intellectual performance (such as IQ measures) and relates these to achievement in some content domain (such as English grammar) after different instructional inputs. These instructional inputs differ from one another in gross terms (e.g., verbal vs. pictorial mode of presentation). Hence neither cognitive performance nor instruction is described in process terms. ATI may ultimately provide a useful vehicle to study information processing in a learning context, but the model will have to be adapted substantially to incorporate process variables.

There is a rich area for research in the interface between cognitive processing theory and other areas, such as knowledge organization, problem solving, direct training of processes and strategies, and ATI. These topics will be discussed in other sections in this chapter (sections 3.2, 3.3, and 3.4).

3.2 MEMORY

Introductory comments

Memory is the core of any processing system. In humans it stores not only past experiences and semantic knowledge, but also information on how to do tasks and solve problems. Brown and Campione (1981) argue that multiple and reflective access to knowledge is the hallmark of intelligent activity. Voss (1979) points out that in problem solving and many other cognitive activities memory structures may be created which will be used later in solving other problems.

Systems have both structural and functional characteristics. Structural aspects are often simpler to understand because these are usually more static. The structure of a large corporate office block, for instance, can be described quite simply and effectively by a set of plans. The functions which occur in the building, on the other hand, are less easy to describe or model. Some of these functions are regular and recur in a standardized form (e.g., refuse removal and annual general meetings), but many are irregular, unpredictable, and not standardized (e.g., reallocation of office space and lift repairs).

It is not surprising, then, that progress in memory research has been mostly in the domain of structural modelling. Structure and function are not totally separate concepts, however; many aspects of structure have implications for function, for structure can constrain or facilitate certain functions.

In many types of system, structure is fairly immutable, subject only to the changes wrought by entropy (in a building, this would be dilapidation; in human memory, senility and forgetfulness). Human memory, however, is not structurally immutable; certain gross features may be fairly unchangeable, but other features may change with time and experience. Hence, even the structural aspect of the memory system has dynamic characteristics, and therefore requires sophisticated models to describe it.

One of the most fundamental distinctions made in the structure of memory is between episodic and semantic memory (Tulving, 1972, 1983). Episodic memory receives and stores information about temporally dated episodes or events, and temporal-spatial relations among these events. A perceptual event can be stored in the episodic system solely in terms of its perceptible features. The act of retrieval of information from episodic memory store, in addition to making the retrieved contents accessible to inspection, also serves as a special type of input into episodic memory and thus changes the contents of the episodic memory store. Episodic memory is autobiographical.

Semantic memory is the memory necessary for the use of language. Tulving (1972) calls it a mental thesaurus, a compendium of organized knowledge about words, other symbols, and the relationships among them. Semantic store also contains rules, formulas and algorithms for the manipuation of symbols and concepts. The semantic system permits the retrieval of information not directly stored in it (through the processing of information to derive new products). Information in this store is derived from the episodic store, but is recorded in such a way that all temporal and personal associations are removed. Links between elements are of a formal nature: they are based on abstract characteristics which elements share. Classifying a hammer and a saw together as "tools" is typical of semantic organisation. On the other hand, classifying a hammer and a nail together because they are used in conjunction with each other indicates that both episodic and semantic criteria are being used. Formal systems of thought such as those taught in educational institutions make demands upon and influence the structure of semantic memory.

In the rest of this discussion our interest will be focussed mainly on semantic memory, since this type of memory is of more relevance to our psychometric, educational, and cognitive themes. Brief reference will also be made to working memory, which Estes (1982) classifies as short-term episodic memory. This type of memory is important in problem solving.

Theory

A number of authors have developed theories of the structure of semantic memory. One of the most important distinctions is between declarative and procedural memory (Gitomer & Pellegrino, 1985). Semantic knowledge about the nature of the world is stored as declarative memory. Elements and concepts in this memory are highly structured and interrelated, and it is through this structure that meaning emerges and that the individual integrates his understanding of the world. We will discuss some of the proposed structures of declarative memory in the following paragraphs. Procedural memory contains the store of processes and strategies needed to perform various activities and solve problems. We have already discussed processes and strategies in some detail in the previous section, but did not emphasise there the importance of storage. In order to do a given task effectively, the appropriate procedures and information must be accessed with the minimum of delay. Metamemorial processes play an important role here; only if one knows what procedures are in one's repertoire and how these could be modified or combined can an effective solution strategy be implemented. Some of these procedures refer to memory itself (Atkinson & Shiffrin, 1968; Pellegrino &

Ingram, 1979). Pellegrino and Ingram state that organisation in memory is the product of the processes which the individual uses to store and retrieve information. Efficiency of performance is directly affected by the type of organization in memory.

A two-way interaction between structure and process occurs. The structure of declarative knowledge in a given individual is a product of the processes and strategies used in storage. Conversely, the contents and structure of declarative knowledge are likely to influence the nature of procedural knowledge, as well as the type of strategy which used in a given application. The structure and contents of both declarative and procedural memory tells the scientist much about an individual's cognitive functioning. It is the present author's belief that even more valuable information on cognitive functioning can be obtained by tracking changes in memorial structure and content during instruction, especially if the instructional material has been devised with processing demands in mind. Research of this kind gives the scientist a window on the cognitive dynamics of the individual. In some cases this may be the only way to study these dynamics as it may not be possible to study directly the processes employed by the individual.

Apart from the early associative models, four main types of model have been put forward to describe the structure of declarative knowledge. We shall refer to these as the hierarchical, network, schematic, and dimensional types of models.

In the hierarchical type of model, knowledge is structured in terms of superordinate-subordinate, concept-instance or whole-part relationships. Collins and Quillian's (1972) theory of the structure of memory is an example of the hierarchical approach. A more sophisticated hierarchical model is to be found in Kolodner (1983a,b). Hierarchical theorists typically choose content areas which are "naturally" hierachically organized to illustrate their theories (e.g., the animal kingdom). It appears that this model is too rigid to be used by humans to store all declarative information (see Mandler, 1979a). Some research has cast doubt on whether even good candidates for hierarchical classification (like the animal kingdom) are in fact stored in that way in human memory (see Lachman & Lachman, 1979).

One of the limitations of the hierarchical model is that the relationships between concepts are all vertical and of a basically similar nature. An attempt has been made to overcome this shortcoming in network theories (Norman & Rumelhart, 1975; Stevens, Collins, & Goldin, 1982). Cognitive elements or "nodes" are organized into semantic networks which link elements to one another via various types of relationship. According to Norman and Rumelhart, the meaning on an element emerges from the relationships which it has with other concepts. The theory is quite complicated. There are various types of nodes: Generic concepts, instances of concepts, values of information, propositions, etc. There are also various types of linkages such as: "Is a class member of", "is a", "has as name", "applies to", and "has as part". Representing knowledge soon becomes very cumbersome and unwieldy using this method. The model is not very suitable for representing memory in a dynamic way, as is necessary in problem solving or learning exercises.

A considerable amount of research is being done on schematic models of memory. This approach has been used in devising machine (artificial intelligence) memory as well as in accounting for human memory.

The first main contribution to schematic theory came from Minsky (1974), who called his schemas frames. According to Minsky, frames are data structures for representing stereotyped situations, like being in a certain type of living room or going to a child's birthday party. Attached to each frame are several types of information. Some of this information is about how to use the frame. Some is about what one can expect to happen next. Some is about what to do if these expectations are not confirmed. The "top levels" of a frame are fixed, and represent things that are always true about the supposed situation. The lower levels have many terminals or "slots" which must be filled by specific instances of data. Each slot may specify the criteria which an instance must meet. It is necessary to have tables at a banquet, for instance, but their number, shape, and arrangement is variable. Collections of related frames are linked together into frame systems. Frames may contain pointers referring to other frames which are relevant under given conditions. If a person is shown a time-distance-speed type problem and one of the conditions of the situation is that he should try to solve the problem, then his time-distance-speed frame should point to his arithmetic frame system.

A frame's terminals are normally filled with default assignments. If an individual is told that someone will give him an apple, he may assume that the apple is green until informed to the contrary or presented with a red apple. The default assignments are usually attached loosely to their terminals, so that they can be displaced by new items that fit the current situation better. This aspect of the theory is relevant to an issue which we will discuss later - that of cognitive rigidity. The ease with which defaults can be replaced plays a crucial role in the effectiveness of problem solving, as Luchins (1954) has shown in his classic water-jar problems. Possibly the most important facility in the solution of a series of different problems (whether of the real-life or test variety) is the ability to replace defaults (possibly left there by the previous problem) with more appropriate assignments for the problem in hand. If intelligence is related to the successful solution of such problems, then default replacement (or cognitive flexibility) is an important component of intelligent behaviour.

Another aspect of the theory which has relevance to intelligence is that of frame selection. When no frame obviously fits the situation in hand, some mechanism has to select a frame which is most suited to the situation, and which can be modified (possibly by changing defaults, possibly by more radical changes) to be more appropriate to the situation. Selection of an appropriate frame is dependent on contextual factors and on the individual's goals. Situations can often be represented in different ways, which vary in appropriateness according to the context or problem in hand (see Williams and Hollan, 1981 and Ehrlich, 1979, on the importance of context in recall and action planning). The importance of representation in problem solving has been stressed by problem solving theorists (see section 3.3). Frame selection is a metacognitive activity and can be thought of in terms of the processing theories reviewed in section 3.1.

Gick and Holyoak (1983) have developed a theory which links schemas to analogical transfer. The latter is essential to intelligent behavior, for it is the mechanism whereby existing knowledge structures are put into service in the solution of new problems. Gick and Holyoak state that the schema affords the basis of analogical transfer. Analogies are one-to-one mappings: Each element in one system is associated with a particular point in another system. Mappings which occur frequently may be represented on a schema or by linked schemata. In solving a novel problem, the subject has to find a schema which will allow him to map the elements of this problem onto the elements of the schema. The procedures specified on the schema will then be of use in the solution of the problem. The more abstractly stated the schema is, the more types of analogy it will be able to handle, but the more difficult it will be to link to a specific problem. If we follow Snow and Lohman's (1984) approach (see previous section) then we would expect very abstract schemata to provide analogies useful for solving novel problems which require fluid intelligence; more concrete topic-specific schemata would tend to be used in problems requiring chrystallized intelligence.

Minsky's (1974) theory is appropriate for both semantic and episodic memory. Shank and Abelson (1977) and Shank (1982) have developed the frame concept into what they call "scripts". These constructs have been used in artificial intelligence programs which are intended to have a deeper "understanding" of the material they store than has previously been achieved. This "understanding" has been achieved by storing information with other relevant information. The same information (or a marker symbolizing it) may appear in several storage structures, its meaning and role being influenced by the surrounding information.

All the models discussed so far are of a categorical or hierarchical nature. Categorical and hierarchical methods have been used to systematize information from Aristotle's time. There is, however, another method of systematizing information which also has a venerable history: That of assigning entities a position in multidimensional space.

Theoretical developments in this domain have been minimal, but several researchers who have concerned themselves with "measuring" the structure of memory have assumed dimensional models. A theoretical perspective developed by the present author follows.

Unlike categorical-hierarchical models, dimensional models are well suited to the expression of the dynamic characteristics of learning and thinking. Projection is the mechanism that can be used to alter the distance of cognitive elements from one another. Projection is the equivalent of context. Thinking is not possible until the complexity of cognitive space is simplified by "projecting" selected cognitive elements onto a subspace, this subspace being the context. Elements which may be far apart in the total space may be close together in certain projections. This happens, for instance when a testee is asked in one of the Wechsler subscales to indicate how an elephant and a fly are similar. The distance between cognitive elements will vary according to the projection employed; if the demand characteristics of the problem are such the the distance between certain elements must be minimized, then a projection will have to be selected which achieves this.

The selection of a projection is a metacognitive activity. Consider the following illustration. Imagine a three-dimensional cognitive space represented by a room. Cognitive elements are balls hung from various positions on the ceiling, and at varying distances from the ceiling. A man enters the room and erects a screen in a certain position. He switches the light off, walks to a position some distance from the screen, and directs the beam of a torch towards the screen. Images of some of the balls will be seen projected on the screen. He then moves the screen and repeats the exercise. Images of some of the same balls will appear on the screen, but in different positions relative to one another. The dynamics of the model are introduced by the man with the torch, who plays the role of metacognition. Clearly metacognition is the most difficult part of human information processing to model, hence the need to fall back on the "homunculus" explanation to account for it.

Several authors have attempted to measure the degree of "proximity" between cognitive elements. Friendly (1979) exposed his subjects on a number of occasions to lists of words and required them to engage in a number of sessions of free recall. The serial order of recall was used as an index of association between words. From this, a matrix of proximity between pairs of words was derived.

Rumelhart and Abrahamson (1973) used analogies in their research. According to them, analogical reasoning can be seen as a kind of similarity judgment in which both distance and direction must be taken into account. In the paradigm A:B::C:D the directed or vector distance between A and B is the same as that between C and D. In many psychometric tests of analogy solution, the fourth term is omitted and the subject has to choose an answer from a set of candidates (multichoice format). If D is the ideal answer in terms of directed vector distance, and the subject is given these possible answers: X(1), X(2),...X(n), then the probability that X(i) is chosen should be a monotonic decreasing function of the absolute distance between X(i) and D. In an empirical study using animal analogies and three dimensions (size, ferocity, and "humanness") Rumelhart and Abrahamson found support for their Euclidean model.

Shavelson and Stanton (1975) identify various types of relationship between cognitions or concepts: Superset-subset, attribute, part-whole, and similarity. Their model seems to combine categorical-hierarchical and dimensional characteristics. Shavelson and Stanton gave their subjects 12 concepts relevant to operational systems in mathematics. They were asked to categorize the concepts in three ways: Word association, card sorting, and graph building. The findings indicated that matrices derived from all three methods, when subjected to a scaling procedure, produced very similar structures.

None of the approaches mentioned above try to track changes in structure as a result of experience or learning, but they do constitute a preliminary attempt to represent the structure of knowledge in memory. If Brown and Campione (1981) are correct in seeing the structure of memory as the basis of intelligent behaviour, then mapping the structure of memory, and changes in the structure as a result of instructional interventions or experience with cognitive material, is of paramount importance for the assessment of intellectual capabilities.

Two models which have been put forward are based on overlap and deficit concepts. These concepts refer to the degree of similarity in knowledge structure between the subject's structure and the structure of an expert, or some idealized structure. In an overlap model the assessment of the subject's structure is a function of the amount of commonality between his and the criterion structure, whereas in the deficit model the assessment is a function of the discrepancies between the subject's structure and the criterion structure.

De Jong and Ferguson-Hessler (1986) studied knowledge organization in physics students. The authors used a card-sorting technique to assess the organization of concepts in memory. The content area was a set of 65 problems. These were structured according to six main themes, with subthemes within these. A 65x65 matrix was generated for each person: A "1" was assigned to a cell if both problems in question were placed in the same pile in the card-sorting exercise; otherwise a "0" was assigned. An "ideal" sorting was also undertaken based on the structure mentioned above. The authors developed a technique for comparing the amount of overlap between the subject's matrix and the ideal matrix. The index which they derived correlated substantially with examination results in physics: 0,54 (n=46). The sortings by good problem solvers was essentially problem-type centred, whereas poor problem solvers were more influenced by superficial elements of the problems, such as the specific words used, as well as specific symbols referred to. Chi, Feltovich, and Glaser (1981) obtained similar results.

It is possible that research into knowledge structure may become a major alternative route to information processing research in the study of cognitive competencies. Ideally the two approaches should be married and used to study cognition in a dynamic fashion. This combined approach could be enriched by integrating it with Craik and Lockhart's (1972) "levels of processing" conceptions (see Battig and Bellezza, 1979). Sternberg's (1985b) knowledge acquisition components may help to explain the levels of processing idea. Knowledge acquisition components are processes involved in learning new information and storing it in memory. One of the functions of these components is selective comparison by which encoded information is related to already stored information to maximize its connectedness with this information.

We have spoken briefly about metacognition in connection with dimensional approaches to memory. In the memorial domain, this function is called metamemory. This term was apparently coined by Flavell and Wellman (1977). Brown (1978) states that metamemory is one of the cognitive activities which constitute self-awareness or explicit knowledge of the individual's own workings in problem solving. According to Brown, metamemory might be called knowing when or what you know. "Secondary ignorance" (not knowing when one does not know) is often a cause of failure to deploy resources effectively in doing cognitive tasks.

Cavanaugh and Perlmutter (1982) state that current approaches to metamemory tend to use the concept in different senses. There is disagreement about whether metamemory also includes executive processes. If executive processes are included, then both what a person knows about his memory store and how he uses it is included in metamemory. Only knowledge about the memory store should be included under the rubric of metamemory according to these authors.

Pressley, Borkowski, and O'Sullivan (1985) state that the intelligent person possesses a wide variety of metamemorial strategies. In addition, he is likely to know about the range, applicability, and mode of execution of his strategies; these are also metamemorial aspects. The authors claim that metamemorial procedures are teachable. Peck and Borkowski (1983) believe that one of the reasons for the relationship between metamemory and intelligent behaviour is that metamemory is important in transferring learning acquired in one situation to other (related) situations; this is essential in intelligent, adaptive behaviour.

3.3 COMPLEX TASKS AND CONTENT-RICH DOMAINS

Introductory comments

There has been a tendency in recent years to study cognitive performance in the context of complex tasks or content domains. These tasks are sometimes laboratory problems, and, increasingly, real-life activities such as tasks based on school and university course material. This research contrasts sharply with the type of information processing research in which subjects are given relatively simple tasks in order to assess the basic building blocks of cognition. As we have seen from section 3.1, these simple tasks are strategy-poor; they are hence not suitable vehicles for the study of the metacognitive activities which seem to be closely associated with most conceptions of intelligent behaviour. Complex tasks, on the other hand, are very suitable for this purpose.

Complex tasks are particularly useful in research on learning, especially in research which involves relating learning to aspects of cognitive competence. Earlier studies which found very low correlations between various learning parameters and general measures of intelligence tended to employ fairly meaningless learning exercises, such as CVC-type paired associate learning tasks; such tasks give the subject only limited scope to deploy his metacognitive skills and strategies.

In many earlier approaches to the study of cognitive functioning, there was a tendency to eschew knowledge as unimportant and to concentrate on the individual's responses to "knowledge free" stimuli. Tests such as the Ravens Progressive Matrices resulted from this type of approach. Measures of this kind were thought to be "culture free" and to tap the most fundamental cognitive abilities or potential of the individual. Although these tests may give an indication of the richness of the subject's repertoire of highly abstract and generalized strategies, they do not give any indication of the individual's strategic performance in content-rich domains which require the acquisition and organization of a large number of facts and specific strategies. Although highly generalized procedures are useful in the solution of novel problems, they are not the most appropriate or powerful methods for problem solution in knowledge-rich areas (Glaser, 1984).

The "content-free" approach to assessment is somewhat analogous to the British public school approach to education in the nineteenth century. Here the attitude was that once a pupil had successfully come to grips with the rigours of Mathematics, Latin and Greek, he would have the right basic skills for high-level administrative positions in the "Colonies." Today this educational approach has been replaced by one which concentrates on teaching the necessary specific skills required for a particular career.

Since content-free evaluations are at best poor predictors of an individual's likely performance in a content-rich domain, it becomes necessary to study performance in content-rich domains themselves. If one adopts this approach, a problem immediately presents itself. There are "so many" content-rich domains. Where is one to begin? This is a difficulty not inherent in the content-free approach.

There is no magical resolution to this problem; all solutions involve compromise. One possibility is to study performance in some generalized content-rich area which appears to require the application of skills which are generally regarded as important in intelligent behaviour. Sternberg (1986a) points out that abilities differ in generality and necessity. General abilities are required for a wide range of cognitive tasks; Sternberg believes that metacognitive processes like planning, monitoring, and evaluation solutions are high on generality. Necessary abilities are those which have to be used to do a particular task: There are no alternative solution "routes" which avoid the use of the ability. Sternberg believes that the abilities that should be most central to our conceptualization and measurement of intelligence ought to be those that are general to a broad range of tasks and that are necessary to the performance of at least a substantial proportion of the tasks to which they are general. It appears that these criteria are important ones to bear in mind when selecting a generalized content-rich area. Knowledge acquisition and usage as well as task performance should be studied in areas which make demands on general abilities such as those which are called upon in metacognitive processing.

One of the advantages studying performance on complex tasks is that these tasks are good vehicles for the study of dynamic aspects of cognition. The solution of most complex tasks or problems involves the application of a string of cognitive activities. The challenge to the test constructor is to devise instruments which require the subject to externalize the main steps in his cognitive processes so that a record of these can be obtained.

This approach can be used in the context of educational or training programs. A combined approach of this type can be used effectively to study training-performance interactions, especially if training is designed within the framework of process theory and measures are designed to be sensitive to relevant process aspects of the individual's performance.

Problem solving

Much of the research into performance on complex tasks has been done under the rubric of problem solving. Problem solving ability is clearly related to other concepts like reasoning and intelligence. Sternberg (1982) states that reasoning, intelligence, and problem solving are so closely related that it is difficult to tell them apart. Certainly problem solving involves reasoning and the application of strategies and processes which are generally regarded as features of intelligent behaviour. Most current intelligence tests are composed of items which require reasoning and problem solving activities. Maltzman, Eisman, and Brooks (1956) found that performance on a classic problem solving task (determining which object, of a set of identical-looking objects, had a mass which differed from the others) was related to performance on an abstract reasoning task. The size of the relationship between performance on a problem solving task and scores on a reasoning or intelligence test depends on the number of components and metacomponents which these tasks share in common.

Resnick and Glaser (1976) believe that a major aspect of intelligence is the ability to solve problems and that careful analysis of problem solving behaviour constitutes a means of specifying many of the psychological processes that intelligence comprises. According to these authors, intelligence involves the assembly of components already in an individual's repertoire of competence. A similar procedure is required in the solution of most new problems. Resnick and Glaser define intelligence as the ability to acquire new behaviour in the absence of direct or complete instruction. This definition appears to distinguish intelligence from problem solving, but the distinction is only superficial. Both problem solving and intelligence as defined above involve the integration of simpler

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cognitive procedures into more complex ones, without benefit of clear instructions on how to do this. This theory bears some resemblance to Snow and Lohman's (1984) process theory of intelligence (see section 3.1) but there are also differences between the two approaches. Resnick and Glaser's "evolutionary" theory places an emphasis on increasing complexity, whereas Snow and Lohman's theory emphasises malleability in the assembly of systems to accomplish new tasks. Presumably, transfer of experience or training is important for both theories (see Hunt & Pellegrino, 1984). Transfer will be discussed in the next section.

Problem solving cannot be discussed without considering memory. According to Polson and Jeffries (1985), the solution to a problem involves a search through a problem space. The problem space is the solver's representation of the task. This representation is constructed by two sets of mechanisms: General understanding processes that can be applied to any problem, and knowledge of the specific domain. The schemata of the individual (see Minsky, 1974) are used in the representation of problems.

There are multiple ways of representing most problems. The selection of an appropriate representation for a given type of problem or for a given context is often crucial to the successful solution (or the ease of solution) of a problem. Selection of an appropriate representation is clearly a high-level metacognitive skill which is strengthened by experience in solving a variety of problems in a given knowledge domain.

Kotovsky (1985) studied difficulty and representation in what is called "Tower of Hanoi" problems. In the classic representation of this problem, the subject is required to move disks of various sizes from one stack to another. Isomorphic problems can be generated which are identical in their fundamental structure, but which superficially appear to be very different. Such problems have one-to-one mappings onto one another (Simon & Hayes, 1976). Isomorphs often differ in their operators; in the Tower of Hanoi problem, the operator is of the "MOVE" variety, whereas in some of its isomorphs the operator is of the "CHANGE" variety. Both types execute transformations. CHANGE problems seem to be more difficult than MOVE problems, possibly because CHANGE problems tend to have a more abstract representation. In the problems mentioned above, the surface structure strongly influences the subject to represent the problem in one way or another. In many problems, however, the mode of representation is not strongly suggested by the material, and it is up to the individual to choose an appropriate representation. Problem solution may be facilitated by representing a problem as analogous to one already solved (Hayes, 1978) but the problem solver has to have sufficient content and procedural knowledge to be able to distinguish genuine analogies from false ones.

One of the reasons that representation is so important in problem solving is that a given representation usually has one or more search or solution procedures associated with it (Richardson, 1983). These procedures are evolved from previous experience in working with problems which were represented in this way. A given solution strategy may not be activated unless a particular representation is used to express the problem. In general, people who adopt abstract-propositional representations may be successful at solving a wide variety of problems of a given type, because representations of this type can be generalised more easily than concrete representations; generalized representations facilitate transfer of solution skills from one type of problem to another. Lower ability individuals may have difficulty, however, grasping and using abstract representations. It is for this reason that Snow (1981) and Snow and Lohman (1984) suggest that more concrete methods be used to teach lower ability individuals.

In the previous section, mention was made of two types of knowledge: Declarative and procedural. These concepts are also relevant to problem solving research. There are strong interactions between structures of (declarative) knowledge and cognitive processes or procedures, as we have seen in the previous section. The acquisition of new procedures through experience or training can result in changes in the structure of knowledge, and vice versa. Nickerson, Perkins, and Smith (1985) question whether a strong distinction can be made between thinking skills and knowledge. The vast majority of people who have made great contributions to their fields have not only been effective thinkers; they have known a lot about their areas. Glaser (1984) states that a person may be very intelligent because of local features of his "knowledge-organizing knowledge" rather than because of global qualities of his thinking. This still leaves one in a state of uncertainty, however, as to the origin of individual differences in knowledge-organizing knowledge. The "g" concept is not convincingly debunked by this argument; in fact the argument could offer adherents of a monistic theory of intelligence a new way of looking at "g" -- in the structuring of knowledge-rich domains rather than in the solution of rather sterile, almost knowledge problems such as one finds in the Ravens Progressive Matrices. Whatever one's position on this issue, the fact remains that problem solving research will yield much more worthwhile results if structure of knowledge is seen as an essential part of this research.

In the light of the above discussion, it comes as no surprise that the meaningfulness of the information with which an individual is required to work is related to his success in solving problems. Meaningful data can be integrated into existing schemata easily; in fact this data is meaningful for this very reason. If a problem can be integrated into existing structures, solution strategies associated with these structures can be activated. Mayo and Greeno (1975) administered to their subjects problems composed of meaningful and nonsense material. As expected, nonsense problems took longer to do. The authors believe that performance on meaningful problems was facilitated by the use of "look ahead" strategies which could be accessed and activated once the material had been related to existing cognitive structures.

Problems can be classified into various types (see Greeno, 1978). In all problems, however, a current condition exists and another condition or state is desired (Dieterly, 1980). Various transitional steps are required to move from the initial state to the goal state. Both Dieterly and Chi and Glaser (1985) make a distinction between well-defined and ill-defined problems. In an ill-defined problem, the initial state is not precisely known, although the goal state and possibly even the transitional steps may be known. In a well-defined problem, the initial state is known precisely; the goal state and transitional steps may or may not be known with precision.

The problem variety which appears to be the most useful for the type of research issues considered in this report is that in which the subject is given a well-defined starting situation and is required to generate the steps required to reach a well-defined end-state. This type of problem is well suited to the study of strategic aspects of the individual's performance. Not all problems falling in this category are suitable vehicles for the study of a given research issue; the psychologist must develop problems which have the right characteristics to study the research issues which he is investigating.

Apart from the superficial features of the problem, the researcher must pay attention to the problem space, the operations available to the individual, and various state points in this space. These factors place constraints on the individual's freedom of action in the solution of the problem. The concept of problem space was formalized by Newell and Simon (1972). A problem space encompasses all the states which the problem can be transformed into under the constraints of the allowable operations. Egan and Greeno (1974) define well-defined problems as follows: Such problems consist of a set of permissable problem states, S, and a set of transformations, T. Problem states can be represented as n-tuples $s(i)=\{d(1),d(2),....d(n)\}$, where $s(i)$ is an element of the n-dimensional state space S. Each $d(j)$ is a value on dimension j. A value need not be numerical. In chess, for instance, states may be coded using board locations as the dimensions and the names of pieces as values. Each $t(k)$ which is an element of T represents an operation that is permissable within the rules of the problem. These transformations map sets of problem states into other states. One transformation may follow another only if the intersection of the range of the first transformation and the domain of the second includes the problem state that results from the first transformation.

Problem spaces can vary enormously in size, from infinitely large to trivially small. As a rule of thumb, the most useful spaces for information processing and strategy research are those which are finite and large enough to permit a variety of paths (sequences of state transitions) to reach the goal state. Very limited spaces do not give the researcher the opportunity to study stylistic or strategic differences in individual performance, and very large spaces present problems in evaluation. The reader is referred to Simon and

Reed (1976) for a practical illustration of how problem space can be represented (the space in this case is the rather small space of valid states in a version of the "Missionaries and Cannibals" problem).

Earlier work on problem solving tended to concentrate on cognitive flexibility and insight (Duncker, 1945; Katona, 1939; Luchins, 1954; Wertheimer, 1945). Later researchers broadened their horizons to investigate a number of strategic phenomena. An "intermediate" group of researchers (e.g., Bruner et al., 1957; Johnson, 1978) tended to produce theories of problem solving strategies which were to some extent dictated by the constraints of their stimulus material (for instance, the "double-change" strategy which Bruner et al. identified is peculiar to the type of concept formation test material used). Most of the recent research has been done in the paradigm of information processing theory; consequently, the research is more theory-driven and instruments are designed to investigate hypotheses rather than to perform exploratory investigations.

Newell and Simon (1972) introduced the concept of the production system (see section 3.1). This concept is little different from a computer program; the problem-solving strategies which these authors developed also owed rather too much to the computer metaphor. The main strategy, "backward chaining", involves breaking a problem into a hierarchically-organized set of subproblems in an effort to find a set of subproblems elementary enough to be solved directly. Although humans may indulge in this type of strategy to a limited degree, it is unlikely to be a method commonly and rigorously used by most people.

Several researchers have attempted to identify elements or phases of the problem-solving process using an approach which is less restrictive than that offered by the computer metaphor. Baron (1982) identifies five phases of problem solving: Problem recognition; enumeration of possibilities; reasoning; revision of possibilities in the light of the previous phase; evaluation. Resnick and Glaser (1976) mention three steps essential to problem solving: Problem detection; feature scanning (noticing features of the problem environment); and goal analysis. Hirschman (1981) identifies a different set of three steps: Representing the problem; production (retrieving relevant information from memory and using this in conjunction with the problem data, all under guidance of the schemata which have been activated); and evaluation (checking the obtained solution against the "ideal" solution).

A few points relevant to the above should be mentioned. It can be seen from the sets of problem sets listed above that metacognitive activities are given prominence. Although there is at present little agreement on what constitutes an adequate set of problem solving phases, the differences among the sets are mainly not because of irreconcilable incompatibilities but because of variations in the emphasis placed on different aspects of the problem solving procedure. It might seem strange to some readers that two of the sets include a phase on problem detection. Problems are not always "obvious"; disadvantaged children in particular may fail to notice problems in their environment which need attention. This issue is dealt with at some length by Feuerstein (1980). It should also be noted that all three of the sets given above place emphasis on the preliminary aspects of problem solving (problem recognition, feature scanning, problem representation). This early "spadework" seems to be essential to successful problem solving. Sternberg (1985a) states, on the basis of empirical findings, that more successful problem solvers tend to spend more time analysing a problem and planning their strategy, and less time on specific information processing steps. Whimbey (1975) found that low aptitude students took a superficial approach to solving problems, and made mistakes because they had failed to read the instructions carefully. These students tended to rush through a problem superficially rather than make a serious effort to understand it. Another important strategy in problem solving is monitoring performance. Skilled problem solvers continuously monitor progress towards the goal state and try to optimize the effectiveness of time and mental resource expenditure. Whimbey's low-performace students had an attitude of indifference to their performance. They showed more interest in knowing the right answer than in how it was obtained.

Child rearing and cultural factors

Before leaving this section, a brief comment is necessary on the influence of child rearing practices and cultural factors on problem solving. Wood (1978) studied problem solving and concept formation in children from middle and lower classes. The mothers were present while the children were working on the problems and were allowed to interact with their children. Lower-class children were encouraged by their mothers to perform the tasks in order to please them or the experimenter. The mothers also encouraged a "self-centred" and "present-centred" approach to problem solving (e.g., classifying objects into a class because one possesses them). Middle-class mothers tended to encourage their children to be task orientated, to break down the task into subgoals, to be motivated by intrinsic rather than extrinsic rewards, to be formal rather than idiosyncratic in solving the problem, and to monitor consequences of given actions. This type of reflective approach to problem solving is likely to result in the storage in memory of information and structures which can be effectively transferred to related problems in the future.

Scribner and Cole (1973, 1981) mention a number of aspects of problem solving and reasoning which are influenced by formal schooling and literacy. Inconsistencies are tolerated more easily in an oral tradition. Aristotelian type syllogisms would not have ever been conceptualized in a non-literate society. Similarly, the use of classificatory schemes is facilitated by the written language. Scribner and Cole believe that literacy facilitates the handling of information in a context-independent way. Hypothetical thinking and formal reasoning is benefited by formal education.

Berry (1984) warns psychologists against making value judgments about the performance of members of other cultures by applying the standards of their own culture. In the "cognitive styles" approach to cross cultural research which these authors favour, a position of cultural relativism is adopted; this approach has on its agenda a search for systematic relationships among abilities which underpin the characteristic style of solving problems within a given culture. One basis for this approach is the work of Ferguson (1954, 1956). According to this theory, cultural factors prescribe what shall be learned at what age; consequently different cultural environments lead to the development of different patterns of ability. Through overlearning and transfer, cognitive abilities become stabilized for individuals in a particular culture, to form the basis of cognitive styles.

3.4 LEARNING POTENTIAL, TRANSFER, AND INSTRUCTION

Introductory comments

According to Resnick (1981), instructional psychology has become part of the mainstream of research into human cognition, learning and development. Researchers are directing their attention to the processes of instruction and learning. Resnick distinguishes three major trends in cognitive-instructional psychology. Firstly, there is a shift towards studying more complex forms of cognitive behaviour (e.g., in the acquisition of curricular material at school). Secondly, there is growing interest in the role of knowledge in human behaviour (e.g., the representation of knowledge and the ways in which knowledge is used in various kinds of learning). And thirdly, many theorists are taking an interactionist approach: Thinking and learning are seen to occur as a result of the mental constructions of the learner.

In addition to the trends mentioned above, there has been an increasing tendency to make education more student-centred (see section 2.5). In order to do this effectively, more has to be known about instruction and learning in cognitive process terms and appropriate measurement instruments will need to be devised, if the research is to take individual differences into account.

Jenkins (1979) has developed a "tetrahedral" model of learning and cognitive behaviour. The four "vertices" of the model are: Characteristics of the learner; learning activities (attention, rehearsal, etc.); nature of the materials; and criterial tasks (recognition, calculation, etc.). In most research there is a tendency to ignore some of these factors and concentrate on only one or two. In earlier instructional research, the characteristics of the learner were either ignored, or described in some gross manner (e.g., by way of an intelligence score). Learning activities were also described in very gross terms, not at the process or metaprocess level. The nature of the materials was often ignored and the criterial activities evaluated only in terms of the "bottom line" (e.g., right-wrong). Nature of the instruction was either not included as part of the research, or was included in a gross way in aptitude-treatment-interaction (ATI) models, which have traditionally not been based on process theory.

Models such as the Jenkins (1979) model have helped researchers to think in broader more inclusive terms when designing research. There has also been a greater realization that interactions between factors must be taken into account. The nature of instruction may, for instance, interact with characteristics of the individual's knowledge base (Entwistle, 1981; Pellegrino and Glaser, 1981). Aptitudes may interact with strategies (Sternberg and Weil, 1980).

If one of the main future uses of testing is to be in a cognitive-instructional-learning nexus, then we should examine some of the theories and concepts which have been generated in this area. We shall begin by reviewing the theories of Vygotsky (1978) and Feuerstein (1980). These theories focus on what is generally called "learning potential" or "modifiability". Biesheuvel's (1972) "adaptability" is a closely related concept.

Feuerstein's and Vygotsky's theories

The central tenet of Vygotsky's (1978) theory is that cognitive skills develop in a social context. Adults and older peers pass on to children the knowledge and skills required in their culture. They allow children to practice new skills by assuming responsibility for other aspects of their activities (e.g., by asking questions about a problem which the problem solver himself should ask). Adults and older peers mediate younger children's experiences; they interpret, give meaning to events, direct attention to stimulus dimensions of importance, and regulate on-going problem solving efforts. In process terms we might say that the adult or older peer takes over many of the metacognitive activities in the execution of new activities, and leaves the learner to perform the lower-level processes.

As the skill is mastered, the strategic and metacognitive activities are taken over by the learner and internalized. If this procedure is completed successfully, then the question asking, regulation and resource apportionment required in the execution of a task is performed internally and independently. Processes which are social property thus become personal property which can be used socially in the teaching of skills to others. There is a parallel between this conception and the Freudian conception of socialization through the internalization of the superego. Vygotsky's theory offers support for the view that metacognitive activities warrant special attention in the study of mental processes. This is particularly true in the domain of individual differences.

Possibly the most remarkable aspect of Vygotsky's (1978) theory is the concept of "zone of proximal development". According to Vygotsky, learning precedes and enables development. Day, French, and Hall (1985) point out that this view is the very reverse of the view taken in Piagetian psychology. They state that Piaget assumed that the child could learn only those things which were congruent with already established developmental levels; this is similar to the "readiness" notion of educators. The basis for Vygotsky's claim was the observation of a distinction between levels of capability that children can display independently and in collaboration with adults or more capable peers.

Hence Vygotsky identifies two developmental levels which have to be determined if one is to discover the relationship of the developmental process to learning capabilities. The first can be called the actual developmental level, the level of development as a result of already completed developmental cycles. When one determines ability using a conventional test, one is measuring this level. The second level is that which can be reached after relevant instructional intervention. The zone of proximal development is "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978, p.86). The zone of proximal development (ZPD) indicates the extent of those functions which have not yet matured but are in an embryonic state, "buds" of development rather than "fruits".

Maximally effective instruction occurs within the ZPD (Day et al., 1985). Instruction directed at the level of completed development can increase the child's knowledge base but will have minimal effect on his cognitive abilities. Instruction directed beyond the ZPD will be incomprehensible and will affect neither knowledge nor cognitive ability.

Brown and Ferrara (1985) state that the mediation process should be slowly withdrawn from the individual as he masters the task. Direct instruction should slowly be replaced by questions and hints, until all help is withdrawn. The level of mastery of a given task can be gauged by the number and explicitness of the hints needed by the person in order to complete the task successfully.

ZPD can also be used effectively as a diagnostic tool in assessment (Bejar, 1984). Despite a long-standing view that intelligence is the ability to learn, IQ tests are in general static measures which reflect the end result of prior learning but do not necessarily provide diagnostic information on the potential for improvement in various areas (Brown and Ferrara, 1985). There are strong reasons to believe that for many people, especially those from disadvantaged backgrounds, the static scores of conventional tests are an underestimate of ability. These scores tend to be correlated with socio-economic standard (SES).

ZPD may be an important concept in acculturation. The person who is moving into a new culture is in some senses in a similar position to the child who is coming to grips with the process required of him in his culture. In both cases, the individual has not "peaked out" at some maximal level of performance. ZPD describes the individual's potential more effectively than current (unmediated) performance level. In a training context the ZPD concept is also important: Trainers need to realize that certain mediations may be necessary in the training of acculturating individuals, as the mediations these individuals received in their native culture may not be appropriate for the tasks and demands imposed by the culture into which they are moving.

Even within a given culture, differences are likely to be found between individuals, especially at younger ages. Parents, teachers, and care-givers can help their charges to develop effective and adaptable "programs" to do the tasks required in a given society. According to Day et al. (1985), the following activities facilitate cognitive development: Adopting a cognitive-rational orientation, employing a Socratic question and answer approach, offering justifications for questions, stressing the importance of intrinsic rather than extrinsic reward in problem solving, and using precise, differentiated language in all problem-related interactions. On the other hand, the use of imperative-normative communications, the failure to give adequate justifications for questions or commands, and the use of imprecise language retards or hinders the development of effective internalized problem solving procedures.

Feuerstein's theory, like Vygotsky's, emphasizes the importance of mediation by care-givers (Feuerstein, 1980; Feuerstein et al., 1985). According to Feuerstein, deficits occur because of cultural deprivation, not because of the inferiority of one culture relative to another. Usually deficits occur because of the failure of care-givers to mediate adequately possibly because they are inadequately integrated into their culture. Individuals in cultural transition are at risk for reasons stated above. Feuerstein believes that individuals differ in the rapidity and ease with which they can modify their cognitive constructs.

Mediation is necessary in the process of socialization within a given culture because each culture has its own "important" and "unimportant" stimulus dimensions. In order to function effectively in a given culture, an individual has to be selective about the dimensions to which he pays attention. Feuerstein et al. (1985) define a mediated learning experience (MLE) as interaction in which an experienced and "intentional" adult interposes himself between a child (or culturally unintegrated person) and some stimulus and alters the stimulus prior to its perception by the individual. The mediator frames and filters the stimulus and interprets it for the individual. The mediator also interposes himself between the individual and his response, regulating the level of impulsivity of his behaviour.

The more MLE interactions an individual has received, the greater his ability to benefit from direct exposure to stimuli and to be cognitively modified. MLEs enable the individual to establish in himself modalities of interaction with stimuli that go beyond the limited field of perceived experience. The propensity to link, organize, relate, and transform relationships and to employ representational, inferential, and hypothetical modes of thinking are all to a large extent products of MLE interactions.

Mediationally deprived individuals typically are deficient in a number of areas of cognitive functioning. Feuerstein (1980) has developed instruments and procedures (the Instrumental Enrichment program and the Learning Potential Assessment Device) to assess modifiability and provide remedial MLEs which are designed to generalize to a wide variety of task situations. Feuerstein does not administer his instruments in a standardized manner. Interventions may be interposed at any stage if benefit is to be gained from this. In sensitive hands the procedures may be effective, but they are not designed to be applied on a large scale by people who have had a fairly brief course of training. Feuerstein's techniques are therefore too expensive to be applied in many contexts and the measures are applied in such a non-standardized way that across-person comparisons are not possible. The technique is essentially clinical. A further problem is that the approach adopted is not fully cognitive-process orientated. Feuerstein has to a large degree gone his own route without reference to "mainline" American research.

Identifying the exact areas of impairment in the search for deficient cognitive processes is done by Feuerstein (1980) through the use of a cognitive map. This map aids in the categorization and definition of the constituents of mental acts. The cognitive map, or model of cognition, has a number of "parameters" which serve in the definition and categorization of various cognitive activities. Feuerstein (1980) identifies seven of these: Content, operations, modality, phase, level of complexity, level of abstraction, and level of efficiency.

Content refers to the subject matter on which given mental acts must be performed (e.g., geography, philosophy). Operations are the cognitive manipulations that have to be performed on the stimulus material, or on information in storage, in order to achieve a given end (e.g, identification, seriation). The modality of presentation of the stimulus material is the "code" in which it is expressed: Figural, pictorial, numerical, symbolic, verbal, or a combination of these. Phase refers to the stage at which a mental act takes place; Feuerstein distinguishes three phases: Input, elaboration, and output. Level of complexity refers to the quantity and quality of units of information necessary to produce a given mental act. (The quality of a given stimulus is influenced by its familiarity: The more novel the stimulus, the more complex.) By abstraction is meant the "distance" between a given mental act and the object or event on which it operates. A highly concrete act could involve operating on the objects themselves (e.g., sorting cards), whereas an abstract act involves performing mental operations of representations of objects (e.g., applying a classificatory procedure to a set of hypothetical objects). Efficiency is somewhat different from the other parameters in that it refers to the individual rather than to the stimulus material. Efficiency includes speed and precision of performance. Clearly, the type of "program" used by the individual will have an impact on the efficiency with which a task is done.

According to Feuerstein, the cognitive map can be used to localize processing deficiencies by devising techniques to examine performance in different sub-areas of the map. By holding certain parameters constant while varying others, domains of deficiency can be pinpointed.

We shall now examine some of the operational deficiencies which Feuerstein (1980) identifies. Feuerstein's approach is somewhat developmental, but not rigorously so. Certain operations are possible only after other operations have been mastered. More "advanced" operations may use simpler operations as components. We shall follow Feuerstein in dividing operations into three classes (input, elaboration, and output). The assignment of an operation to a given class is somewhat arbitrary in some cases. The lists given below are edited; only those deficiencies which appear relevant to the aims of this report are included.

Input deficiencies

1. Blurred and sweeping perception (this does not refer to limitations in the perceptual hardware).
2. Unplanned and impulsive exploratory behaviour.
3. Lack of verbal tools and concepts (this can affect discrimination, as different stimuli cannot be given different names).
4. Impaired temporal and spatial orientation (defects in relational thinking).
5. Impaired conservation of constancies.
6. Inadequate precision and accuracy in data gathering.
7. Failure to deal with more than two pieces of information simultaneously (e.g., failure to consider both row and column information in Ravens Matrices type problems).

Elaborational deficiencies

1. Failure to perceive and define a problem (which implies failure to notice incompatibility between two or more sources of information).
2. Failure to select relevant cues in a problem (relevance is determined largely by the goal of the problem solving exercise).
3. Lack of or impaired spontaneous comparative behaviour.
4. Poor integrative behaviour.
5. Narrowness of cognitive field (limited number of units of information processed at one time, resulting in failure to finish in the allotted time or the failure to do all necessary processing).
6. Failure to recognize the need for logical evidence in decision making.
7. Inadequate strategies for hypothesis testing and inferential thinking.
8. Inadequate planning behaviour.

Output deficiencies

1. Problems in communicating.
2. Blocking of responses.

3. Trial and error responses.

The Instrumental Enrichment program consists of 15 instruments. Each is intended to focus on a particular cognitive deficiency, but each also addresses itself to the acquisition of many other prerequisites of learning. Inspection of the tests reveals that they are rather multidimensional. Although these tests may be useful in the hands of a clinician, they are not suitable for use in an industrial and mass-testing context.

In the Learning Potential Assessment Device (LPAD), a test-train-test procedure is adopted. The test material used is drawn from conventional tests like the Ravens Progressive Matrices. Brown and Ferrara (1985) state that the LPAD lacks a fine-grained description of the prompts and aids given to the child in the training session of the sequence. The examiner gives hints as needed. As a consequence of this, much of the diagnostic power of the instrument is lost.

Brown and Ferrara (1985) have attempted to interpret Feuerstein's (1980) theory in process terms. They believe that the types of deficits which Feuerstein describes as commonly occurring in disadvantaged Israeli adolescents are what processing theorists in the Unites States have commonly called metacognitive problems. According to these authors, the following are the most common deficits in learning:

1. Deficits in a variety of systematic data-gathering, checking, monitoring, and self-regulatory mechanisms. These are what might be called "autocritical skills".
2. Tendency to follow instructions blindly; lack of adequate question-asking skills. Failure to overcome comprehension problems with remedial strategies.
3. Tendency to treat each problem as *if* it is a new problem, regardless of past experience.
4. Slow development of learning sets; slow transfer of past learning; inadequate learning from past experience.

Intervention programs such as those of Feuerstein (1980) involve the taking over of metacognitive activities by the psychologist. The role of the psychologist as a metacognitive agent is slowly lessened as the subject learns to apply these strategies for himself. One of the important aims of Feuerstein's approach is to promote the generalization of metacognitive skills. The individual is made aware of the breadth of applicability of the strategies which he is being helped to master. The intervention is partly a metalearning exercise: The participant learns how to learn, so that information acquired can be applied optimally in future problem solving exercises.

Research into modifiability or ZPD and its practical applications is still in its infancy. Feuerstein (1980) reports on research in which his own techniques of enrichment are compared with conventional methods (e.g., giving individuals extra lessons in school subjects). Results were encouraging for the Feuerstein Instrumental Enrichment approach, but not dramatically so.

One of the earliest studies on modifiability was conducted in South Africa. Lloyd and Pidgeon (1961) applied two forms of an IQ test to Blacks, Whites and Indians in junior schools. The two administrations of the test were separated by a coaching intervention in which the concepts which occurred in the test were taught to subjects. Blacks showed the greatest increase (14.6 points), followed by Whites (10.6 points), and Indians (6.1 points). Hence the most disadvantaged group (Blacks) showed the greatest modifiability, but the most advantaged group (Whites) did not show the least modifiability. Samples varied from 86 to 105.

How is advantagement related to modifiability? This is a difficult question; at least three major factors seem to be at play. Many disadvantaged individuals may have had a paucity of MLEs for social and economic reasons; this can reduce modifiability (Feuerstein et al., 1985). On the other hand, disadvantaged individuals have often not realized their potential as fully as advantaged individuals due to lack of educational opportunity; from this point of view, less advantaged individuals should be more modifiable than their more privileged counterparts. Thirdly, age probably plays a fairly complex moderating role. At very young ages modifiability should be low due to a limited number of mediated learning exposures and other maturational factors. Modifiability should increase with age until certain ability limits start having their effect (this argument assumes that there are such limits). Thereafter, there may be a plateau followed by a slow decline in modifiability due to aging and the entrenchment of preferred modes of behaviour. This curve may differ somewhat for groups at different levels of advantagement. Less advantaged individuals may take longer to reach their peak due to impoverishment of learning opportunities, and they may start declining sooner due to the unchallenging nature of their work. The combined effect of these factors makes it difficult or impossible to make any hard-and-fast statements about the relationship of advantagement to modifiability. However, there is not likely to be a consistent positive correlation between SES and modifiability as there tends to be between SES and conventional ability measures.

Brown and Ferrara (1985) report a study in which high IQ (mean 122) and average IQ (mean 101) third-graders and fifth-graders were administered a letter series task of the type devised by Simon and Kotovsky (1963) (See Butterfield, Nielsen, Tangen, & Richardson, 1985, for a detailed analysis of this type of series.) A pre-test and a post-test were administered; modifiability was assessed in terms of the number of hints required by the individual before he could be relied upon to answer a given type of item correctly. Transfer was also measured by giving subjects problems of a type which differed somewhat from those given in the pre-test and post-test. The following were the main findings:

1. There was a tendency for high IQ subjects to learn more quickly (need fewer hints to reach a criterion of performance on the pre-test), but this tendency was only of modest strength. There were appreciable numbers of high IQ slow learners and low IQ fast learners.

2. Third-graders tended to require much more assistance than fifth-graders as transfer problems departed more drastically from the ones originally learned.

3. High IQ subjects transferred knowledge more effectively than low IQ subjects, but there were appreciable numbers of low IQ high transferers and high IQ low transferers.

4. High transferers tended to be fast learners and vice versa, but, as above, the relationship was far from perfect.

The authors suggest that the three variables modifiability, transfer, and intelligence can be used as the basis of an eight-way classification system (the subject is classified as high or low on each of the three variables).

Holzman, Glaser, and Pellegrino (1976) pre-tested children on Kotovsky and Simon's (1973) letter series test. An experimental group received training on detection of inter-letter relations and series periodicity, while the control group did an unrelated task. Both groups were post-tested on a parallel version of the test. The Kotovsky-Simon letter series problems have the advantage that exactly parallel items can be created and that the difficulty of items can be quantified a priori. (For most other types of problem, a latent trait model should be used to match pre-test and post-test items -- see Embretson, 1985, and Whitely & Dawis, 1974.) The results of the Holzman et al. study showed that a considerable amount of learning occurred merely from doing the pre-test: The control group performed significantly better in the post-test than it did in the pre-test. The improvement of the experimental group who received the intervention was, however, two-and-a-half times greater than the improvement of the experimental group. The difference was greatest in the more difficult items. The authors state that the training seemed to have given experimental subjects a systematic technique that could be used successfully on items of all difficulty levels.

Training interventions vary in efficacy. Whitely (1974) did a ZPD type study with six treatment groups, a control group and experimental groups with various combinations of practice, feedback, and structure (teaching of relationships between elements). It was found that both feedback and structure was necessary in order to achieve a significant improvement in performance.

Shochet (1986) administered the NIPR's Pattern Relations Test and Deductive Reasoning Ability Test to advantaged and disadvantaged first-year Arts students at the University of the Witwatersrand. A Feuerstein-type intervention was administered on the principles underlying the test items. Number of courses passed was the criterion. In both the advantaged and disadvantaged groups, none of the scores, conventional or modifiability, correlated significantly with the criterion. The author then split the disadvantaged group into two subgroups on the basis of modifiability. In the subgroup composed of less modifiable individuals, there was a correlation of 0,55 between the Deductive Reasoning Ability Test and number of credits. In the subgroup composed of the more modifiable individuals, there was a non-significant relationship between these two variables. This illustrates the inapplicability of conventional ability scores for predicting the performance of modifiable people.

The failure of the modifiability scores to predict performance may be due to the unreliability of these scores in this study. Modifiability should be assessed using instruments especially constructed to maximize the mean and variance of the difference score. This is necessary in order to reduce the unreliability of difference scores. Instruments which produce small difference scores are of limited use, as the mean difference score is often smaller than the standard error of measurement.

The studies mentioned above are of a largely academic nature. The interventions are brief and the object of the remediation highly circumscribed. At the other end of the continuum are studies in which massive interventions are undertaken over a long period of time. An example is the Milwaukee Project, reported on by Garber and Heber (1982). This project focussed on 40 economically disadvantaged mothers with infants from three to six months. All these mothers had IQs of less than 75. The project provided children with preschool education virtually year-round, until they entered school. This education concentrated on problem solving and language skills. The mothers also received attention - remedial education, guidance in home management, and job training. At the age of 10, the treatment group had a mean IQ of 104 while a control group had an IQ of 86.

In a similar study, based on what was called the Abecedarian Program, less impressive results were obtained, and initial gains tended to fade away (see Ramey, Mc Phee, & Yeates, 1982). Garber and Heber (1982) speculate that the Milwaukee Program was more successful because the mothers received an intervention in this study (in the Abecedarian Program, mothers received no special attention). This explanation makes sense from the Vygotsky-Feuerstein point of view. The interventions received by the mothers helped to improve their level of cultural integration. Consequently, they were able to give their children better quality MLEs.

Transfer

Transfer is related to modifiability, but there are also certain differences between the concepts. These are illustrated in the Butterfield et al. (1985) study described above. In research on modifiability, the content domain remains constant in pre-test and post-test, whereas in a transfer study, a certain amount of restructuring and integration of information is needed in order to do the post-test tasks. Also a formal intervention is not always a feature of transfer research.

Transfer is closely related to what has been called learning set (Harlow, 1959). Learning set tasks involve the transfer of experience to analogous tasks. Harlow refers to learning set as "interproblem" learning as opposed to "intraproblem" learning. Learning set is "learning to learn". Indices of interproblem learning are amount of time taken to learn an analogous task, or number of errors committed before an analogous task is mastered, or simply number of items answered correctly within a given time limit on an analogous task.

Several cognitive and learning theorists believe that the capacity to transfer learning to new applications is the core of intelligence. Campione, Brown, and Bryant (1985) point out, however, that the relationship between intelligence and transfer exists only for learning tasks in complex domains. Transfer in complex domains seems to depend on the repertoire of strategic (metacognitive) processes which an individual has, and on the nature of his knowledge schemata (Brooks, Simutis, & O'Neil, 1985; Campione, Brown and Bryant, 1985; Glaser, 1984). In assimilating new knowledge, schemata have to be modified or even created. For transfer to be possible, information must be stored in such a way that is usable in situations analogous to the one in which the learning took place; in addition, strategies must be available for the retrieval of the relevant schema or schemata and for the modification of these (e.g., by replacing schema default values). Learners who realize the usefulness of knowledge for future applications facilitate transfer by creating generalized schemata which are usable in many contexts. More specific schemata might also exist for tasks which are done regularly. Kane (1984) states that successful learners and problem solvers often make multiple records of information for different purposes, using different modes of storage (e.g., visual-spatial vs. verbal-analytic).

The process of setting up appropriate knowledge structures in itself places demands on the ability to transfer information. Brown and Campione (1981) point out that most instruction is incomplete. In order to make a full record of a particular instructional input, the "gaps" must be filled in. This demands the transfer of knowledge from other knowledge structures.

Campione and his colleagues have studied transfer differences in groups of mildly retarded, normal, and gifted children. In the studies reported in Campione, Brown, and Bryant (1985), tutors were used to help average and above average intelligence subjects attain the right answers to series problems using a minimal help (hint) strategy. In a second phase, subjects were given items which were essentially the same as those encountered in the first phase (these were called maintenance items), as well as items which required a small amount of transfer (near transfer items) or a large amount of transfer (far and very far transfer items). On the maintenance and near transfer items, the groups did not differ. On far and very far transfer items, however, large differences emerged. Even though both groups learned the original principles to the same criterion, the above average subjects transferred more broadly. Similar results were obtained by Campione et al. in a study which included normals and retardates, except that even the maintenance items were not done perfectly by the retardates.

In a study by Campione, Brown, Ferrara, Jones, and Steinberg (1985), two groups of subjects were selected, both with a mean mental age of 10 years. However, one group (the retarded group) had a chronological age of 14,5 years, while the other group (the normal group) had a mean age of 9,1 years. The experiment had five phases: Pre-test, training, maintenance, transfer, and post-test. The material used for testing was a Ravens-type task, with only three concepts involved: Rotation, imposition, and subtraction. Pre-test and post-test were identical. The training phase was carried out on PLATO terminals. An item was presented and the subject had to construct the correct answer (instead of choosing from a set of alternatives) by activating commands using the touch-sensitive screen. At any stage during this process the subject could ask for a hint. Two scores were available: Number of hints and number of errors in the subject's answers. Maintenance items were presented on two separate occasions. In the first session the subject had to solve four items of each type; these were presented randomly, not in block format as had been done in training. In the second maintenance session, subjects had to solve two more of each type, but in addition these were interspersed with the transfer items which involved a combination of principles.

The main results were as follows. Pre-test scores were not significantly different for the two groups. Also there was no evidence of differences on training scores. There was, however, evidence of learning to learn in that later types of items were mastered better than would be expected from the pre-test statistics. When the subjects were required to make flexible use of the matrix rules, pronounced group differences in favour of the normals were obtained (i.e., in maintenance, transfer, and post-test sessions). In these sessions the subjects had to identify the kind of problem and, in the transfer problems, integrate principles learned separately in the training session. The differences occurred as soon as the problem types were no longer "known" or marked by their context. The experimenters concluded that their data provided support for the importance of transfer mechanisms to theories of intelligence. Ability-related differences appear to become more marked as the degree of transfer increases.

Belmont and Butterfield (1971) found that if retardates are given detailed instruction and coaching on the strategies needed to do a particular task, they become as proficient as normals at the task. Retardates fail, however, to transfer this strategy knowledge to related or analogous tasks, whereas normals routinely do this, at least for near transfer problems. The difficulty experienced by low ability individuals is therefore not so much in the execution of the processes required to do a given task, but in the metaprocesses required to select appropriate stored information (i.e., perceive the analogy or similarity between a given problem and a new one) and modify procedures to suit the new problem. Clearly the "intelligent" storage of information is essential to this process, as we have observed above.

Individuals with learning disabilities (LD) differ from retardates in that their academic difficulties are specific and circumscribed (Wong, 1985). Like retardates, however, LD children fail to ask themselves appropriate questions when doing a task, and often do not evaluate their responses to the task. They may not lack the requisite knowledge to do a task, but fail to implement it appropriately. This deficit again points to a metacognitive problem, possibly due to insufficient or inadequate MLEs.

Instruction and learning

It is important to discuss instruction in this report because of the importance of adopting an integrated approach to testing and training, of assessing performance as a function of the processing characteristics of the individual, the processing demands placed by the instructional input, and the interaction between these two sets of factors. In this subsection we shall look at some of the themes which are emerging in instructional psychology.

Knowledge

As was mentioned in the previous subsection, knowledge and knowledge structures have an important effect on what is learned. Pellegrino and Glaser (1981) state that instruction involves presenting students with a network of knowledge that can be assimilated into the students' existing network. Gallagher (1979) points out that different instructional methods may result in knowledge structures which are fundamentally distinguishable. Greeno (1974) reports a study in which two types of training were given to subjects on the calculation of binomial probabilities. In one type, subjects were given some conceptual background; in the other type, subjects were taught rote methods for doing the calculations. The results showed that the identification of problem type was easier for those who had received the conceptual training; the rote-trained subjects did the calculations more easily and quickly, however. In the conceptual training condition, the information was presumably more extensively integrated into existing knowledge structures, and hence more "meaningful" to the subjects. Although this state of affairs (integration of knowledge) is generally seen as a desirable, it may not always be so. The goal of the instruction should always be kept in mind. If the aim is to install with minimal time delay an efficient, straight-forward, and usable "program" in memory, then the cognitive structures generated by a rote teaching input are to be preferred to one concentrating on making concepts meaningful.

Reigeluth (1983) states that prior knowledge is used to facilitate the acquisition, organization, and retrieval of new knowledge. He lists seven types of knowledge: (1) arbitrarily meaningful knowledge to which rote knowledge can be attached; (2) superordinate ideas which can be used as "ideational scaffolding" for new knowledge; (3)

"co-ordinate ideas" which serve associative, comparative, or contrastive functions; (4) subordinate ideas and (5) experiential knowledge, both of which serve to instantiate or concretize new knowledge; (6) analogic ideas which relate new knowledge to highly similar knowledge that is external to the content area of interest; (7) cognitive strategies which provide appropriate cognitive processing during the acquisition of knowledge.

Reigeluth (1983) states that a complete model of instruction should take advantage of all these kinds of prior knowledge. Each task is best learned by different subsets of these. Although this is a useful taxonomy of knowledge, its ultimate usefulness will depend on its being integrated in a process model which takes individual differences into account. The author makes some global statements (e.g., he suggests that a general to detailed sequencing of instructional material is appropriate in the Third World), but these statements have little worth unless tied to process theory. The same criticism can be levelled against Bloom's (1956) taxonomy of educational objectives.

Styles of learning and instruction

Attempts to identify styles of learning (with the aim of devising appropriate instructional material) have also not taken sufficient cognizance of process theory. Pask (1976) distinguishes between comprehension learners and operation learners. Entwistle (1981) and Doyle and Rutherford (1984) identify a number of styles including perceptual-analytic, field dependent-independent, impulsive-reflective, and levelling-sharpening. These styles bear some resemblance to what have been called strategic processes or metaprocesses elsewhere in this report, but not enough has been done by style theorists to define styles more precisely in process terms. A metaprocess such as "monitoring performance" can be defined quite accurately in terms of the first-order processes involved, but the same cannot be said about a style like field dependence. If, for example, a theorist defined a perceptual style in terms of a tendency to look for relationships between elements rather than to look for abstract concepts, then this style could be integrated in process theory.

Complex interactions may occur between learning styles and instructional styles. These styles vary in compatibility. Pask's (1976) comprehension learners are likely to feel more comfortable with a conceptual instructional input whereas operation learners may prefer a rote input (see the reference to Greeno, 1974, above).

Research into cognitive style is important according to Frederico (1981) because styles cut across traditional ability domains and because styles are more modifiable than abilities. From our discussion of metaprocesses in section 3.1 it should be clear, however, that care must be exercised in modifying or teaching new styles. This is especially true when the psychologist and subjects are from different cultures.

Adaptive education

The idea that education should be adapted to the individual has arisen partly because of a growing realization that different groups of people may process information in different ways (i.e., they may use different styles). Glaser (1978, 1981) believes that the educationalist should modify his instructional inputs to capitalize on the strengths of the learner. The educationalist should not have culturally-based prejudices about "right" and "wrong" ways of cognizing material. Glaser goes even further and states that ideally, education should not have rigid goals. In most instructional courses, individuals are compelled to learn certain material and to write a standardized examination. Glaser proposes making this more adaptive, in much the same way that an individual who is teaching himself pursues certain topics and ignores others.

Obviously, there are several difficulties and shortcomings in implementing education which is so heavily learner-centred. Even with computerization, there is a limit to which education can be individualized. Further developments in theory are necessary before effective adaptive instruction can be designed. Measurement instruments will have to be created to assess task demands and performance at the process level.

A balanced approach would appear to be one in which both adaptation of instruction to the individual and the adaptation of the individual to standardized instructional inputs play a role. Adaptation of educational inputs should be done where practicable; changing the learner through the training of strategies or metaprocesses should be done where these are essential in order to do a particular task, or where adaptive education is not a viable option. Measurement instruments would be used to assess the effectiveness of both adaptive education and the training of strategies and procedures. These methods should be compared with each other and with conventional education, which does not adapt to the individual and which teaches only course content, not learning and reasoning skills (see Chipman and Segal, 1985; Nickerson, Perkins, & Smith, 1985).

Wagner and Sternberg (1984) believe that in order to improve educational performance metacognitive skills (strategies) must be taught. Transfer or generalization of skills is greatly enhanced if these skills are taught. Belmont and Butterfield (1977) reviewed 114 studies on the teaching of cognitive skills. None of these included the teaching of metacognitive skills, and none reported generalization of training. Belmont, Butterfield, and Ferretti (1982) reviewed seven studies which directly taught metacognitive skills; of these six reported generalization of training.

Aptitude-treatment-interaction (ATI)

The material in a given content domain may be taught in different ways. The mean achievement level after instruction may differ for different instructional treatments; in addition, the relationship between certain psychological characteristics and post-instructional achievement may differ for different treatment groups. An ATI exists whenever the regression of outcome from treatment A upon some kind of information about the person's pretreatment characteristics differs in slope from the regression of outcome from treatment B on the same information (Cronbach and Snow, 1977).

Most ATI researchers have assumed a very simple model. An aptitude is measured; persons are randomly assigned to one of two instructional treatments; an outcome is measured; and the interaction is tested for significance. Cronbach and Snow (1977) state that this design, though of basic importance, is inadequate for many studies. Since characteristics of learners and treatments are "plural" it may be wise to measure more than one aptitude or compare more than two treatments. Outcomes are also plural: The aptitude-treatment combination that serves best to produce one outcome may have a small effect (or even detrimental effect) on another.

It is instructive to compare the traditional correlational (selection) and experimental models with the ATI model. The correlational model ignores any possible differing instructional environments which the student may experience. Whatever intervenes between the aptitude test and the final measure is taken as a single undifferentiated treatment. Experimental research, on the other hand, is concerned with differences among treatments but not with differences among persons. The experimenter tries to remove the effects of individual differences by using a matched pairs design, random assignment, analysis of covariance, etc. He hopes to achieve the optimal treatment for everyone. Underlying this is an assumption that regression lines are parallel for different treatments; only means are of importance. The ATI model combines features of the correlational and experimental models: It combines the regression approach of the former with the group comparison approach of the latter.

In the ATI model, non-parallel lines are evidence of interaction. A flat regression line indicates that, under the treatment in question, the educational outcome is not heavily dependent on the measured aptitude; a steep regression line indicates the opposite. When regression lines cross in a two-treatment model, this indicates that one treatment is more effective above a certain aptitude level and the other more effective below that aptitude level. Unlike the "select-reject" split done in the correlational model, the split in the ATI model is "assign to treatment X" or "assign to treatment Y."

Although the general approach of the ATI model is in keeping with the aims of adaptive education, the model uses constructs which are too global to be of use in diagnosing cognitive lacunae, determining preferred styles of doing tasks, and designing truly adaptive educational material. To achieve such goals, a processing approach is needed.

Although ATI models usually include different modes of instruction, this is not essential for the model ("T" in ATI after all refers to treatment, not instruction). Gavurin (1967) for instance, conducted an ATI model in which subjects had to solve anagrams printed on movable tiles or on paper. Performance in the latter condition correlated much more highly with spatial ability than performance in the former condition. The latter condition placed an extra processing demand on subjects, and individual differences between performance on the two versions of the task could be taken as a sort of measure of spatial ability.

What sort of research vehicle will make it possible to study the teaching-learning nexus at the process level? Snow and Peterson (1985) suggest that the combination of the ATI approach and information processing approach provides the best means of developing a process theory of individual differences in learning: This combined approach will, according to these authors, explain aptitude, learning, and achievement in common psychological process terms and account for the effects of specified instructional conditions on these processes.

In my opinion, one of the shortcomings of the conventional ATI model is that proficiency is not assessed at a number of points during instruction; hence no information on learning curves is available. A further problem is that proficiency itself is too global an index; it merely indicates the number of questions answered correctly in a post-instruction test. What is needed is to devise a method of assessing subjects on a number of knowledge-relevant variables which can be combined to give some indication of the structure of each individual's knowledge.

Time and effort therefore needs to be spent on investigating ways of translating the ATI model into a process-based model which can be used to study changes in knowledge structure in response to different types of educational input.

Task analysis

In order to adopt a process approach to education, sophisticated task analyses of educational material must be undertaken. Gallagher (1979) defines task analysis as the analysis of complex instructional tasks in terms of formal process models. This involves identifying component skills necessary for the task (Gregg, 1976). Diagnostic tests are required to determine which skills a learner already possesses, so that instruction can build on this base, and teach, one by one, the additional component skills required to do the task.

There are several shortcomings in conventional task analysis. Firstly, it ignores styles of task performance: Different styles may involve different sets of components (see Sternberg, 1986). Secondly, conventional task analysis assumes that the components are independent of one another (Wong, 1985). If interactions occur, it becomes necessary to determine what these are. Thirdly, conventional task analysis ignores the importance of metacognition (Wong, 1985). Fourthly, conventional task analysis tends to describe expert rather than novice task performance (Resnick, 1976).

In order to overcome some of these problems (particularly the fourth), DiSessa (1982) has introduced what she calls "genetic task analysis" (GTA). GTA differs from its conventional counterpart in that it has an evolutionary component. The aim of GTA is to identify components of pre-existing knowledge which can become involved in learning of a new body of information. In GTA, "genetically" antecedent partial understandings replace logically derived task demands as basic elements. Conventional task analysis tends to overestimate the newness of knowledge and the amount of structuring required. In practice, the way that knowledge is functionally encoded involves a "confluence and complex orchestration" of a number of partial understandings based on previous knowledge. Prior more naive encodings may remain in memory even after more sophisticated representations have been evolved. What might be taken as redundant, ancillary, or simplistic encoding of a concept might serve important functions such as facilitating quick access, providing for robust remembering, and expediting planning.

DiSessa's (1982) ideas are of value from the pedagogic point of view. An effective instructor can employ a series of increasingly sophisticated and comprehensive encodings to facilitate the evolution of complex knowledge structures in the minds of his pupils.

Glaser (1981) points out the usefulness of task analysis from the Feuerstein-Vygotsky perspective. Once the core components in a task have been identified, investigation can proceed on the instructability of these components. Diagnostic tests are clearly necessary in a exercise of this nature, so that changes in componential competence can be monitored throughout the instructional input. Ideally, an exercise of this kind should be embedded in a process-based ATI model in order to study instruction-learning interactions.

3.5 PERSONALITY-COGNITION INTERFACE

In this section we will discuss two constructs which are in the "grey area" between personality and cognition. These are impulsivity and rigidity. According to Baron, Badgio, and Gaskins (1986), these variables are "cognitive" in the sense that they concern attending, perceiving, remembering, and thinking; they resemble personality variables in that they do not involve the limits of performance.

Impulsivity and cognitive rigidity have been selected for discussion because they seem to have a major impact on problem solving and task execution efficiency. Impulsivity and rigidity are apparently broader or more general than metaprocesses or strategies, as each of them has an effect on a wide range of metaprocesses. The term "style" is sometimes used to refer to a particular mode of processing information that is more general than any particular metaprocess. Pask (1976) for instance refers to comprehension and operation learning as styles of learning; each of these types of learning involves a constellation of metaprocesses. It might be appropriate to refer to impulsivity and cognitive rigidity as affective styles of processing information.

The concept impulsivity has gained prominence in psychology largely through the work of Kagan (1976). Kagan sees impulsivity as the opposite of reflection but does not locate them on a single continuum. The vehicle which Kagan uses to assess reflection-impulsivity is the Matching Familiar Figures Test (MFFT). In this test, which exists in a number of versions, the subject is presented with a master figure and has to say which of a set of alternatives is identical to the master figure. The figures are complex (e.g., the markings on the neck of a giraffe). An exhaustive inspection of all aspects of the figure is necessary before it can be said with certainty that a given alternative is identical to the master figure.

Kagan (1976) takes two aspects of performance into account when assessing reflection-impulsivity on the MFFT: Response time and number of errors. He performs median splits on each of these dimensions, and assigns into the "impulsive" category those individuals who are below the median on response time and above the median on number of errors. Approximately two-thirds of respondents are classified into this quadrant and the "reflective" quadrant (long response time, low number of errors) in most studies (see Messer, 1976). The Kagan approach is therefore sample-based and does not classify all individuals into the reflective and impulsive categories.

Baron et al. (1986) objects to the arbitrariness of splitting speed and accuracy at their medians and suggests a "normative" approach. Different tasks impose different requirements with regard to these variables: A pay-off is always involved. One should, according to Baron et al., measure the deviation from the optimum for the task under study. Reflection-impulsivity is assessed from the direction and extent of deviation from the optimum point. (These optima can be determined only in highly structured tasks which permit a statistical model to be applied.)

The relationship of impulsivity to intelligence has been long known. Thurstone (1924) states that the key aspect of intelligence is the inhibition of impulsiveness. He believes that the ability to consider and evaluate possible courses of action without actually engaging in them distinguishes between intelligent and unintelligent behaviour. Although Thurstone flourished well before the time of metacognitive psychology, he appears to be saying that the sort of cognitive control which is today included under metacognition is a prerequisite for intelligent behaviour.

An impulsive style has a number of negative consequences for effective information processing in most contexts. Information is encoded less deeply and less extensively. Brown and Campione (1981) state that multiple access to knowledge is an important feature of intelligent functioning. Incoming information should be reflectively evaluated so that it can be stored in such a way to be optimally usable in future problem solving exercises. Instruction is often incomplete and has to be "filled in" by the student, sometimes through the use of transfer mechanisms. An impulsive style limits the extent to which these processes can be executed (see Borkowski et al., 1983, for empirical evidence in support of this).

Impulsive behaviour not only negatively affects storage of information; it results in poor performance in most problem solving exercises (see Heckel, Allen, & Stone, 1981). Successful problem solving requires careful analysis of the data at hand (Resnick & Glaser, 1976). Impulsive individuals, however, do not exhaustively examine data (Mitchell & Ault, 1979; Rader & Cheng, 1981). Sternberg (1985a) states that intelligent individuals tend to spend relatively more time than others on global planning. Impulsives are not likely to do enough of this type of preparation. Sato (1983) found that impulsives tend to underestimate task difficulty.

It appears to be possible to teach more reflective behaviour (Loper and Murphy, 1985). Feuerstein et al. (1985) claims that impulsivity can be controlled by a mediator who interposes himself between the individual and his response. Ultimately, this control is taken over by the individual himself. Baron (1982) points out that certain social inputs may create a propensity to behave impulsively in inappropriate circumstances. For example, children who are taught to answer quickly when asked a question may carry this over to situations where it is not appropriate (e.g., in examinations). The style used by parents can be taken up by their children (Goldstein & Rollins, 1983). An individual may behave impulsively because he believes that the appearance of self-confidence is more important than accuracy. (In certain contexts he would be right!) Also, the rationalization "I could have done it if I really tried" is available. Baron believes that impulsiveness may result from the same sort of expectations that account for learned helplessness. Impulsive people may expect that further thought will not increase the probability of success. Such an expectation may result from prior failure experiences. For certain people, feedback of results may increase impulsivity and poor performance on cognitive tasks.

We turn now to cognitive rigidity. This concept has a fairly long history in psychology. Duncker (1945) used the term "functional fixedness" to refer to the failure to perceive an object independently of its function. Individuals who could not solve Duncker's problems were unable to restructure the problem data in a new way (e.g., a pair of scissors would not be seen as a potential weight for a pendulum).

Wand (1958) defines flexibility as the ability to devise new methods of solving problems when familiar methods are less appropriate. She points out that the terms rigidity and flexibility have been used indiscriminately to refer to stereotypy in areas of human functioning ranging from motor perseveration to fixity of social attitudes. In an empirical study, which included a variety of measures of different "types" of rigidity, she found no evidence for a general rigidity factor. This finding contradicts Rokeach's (1948) standpoint that there is such a factor.

We shall be circumscribed in our definition of rigidity and consider rigidity-flexibility as the degree to which an individual can change strategies and modify (or reassemble) production systems in order to perform a set of tasks successfully. Snow (1981) associates this with fluid intelligence (see section 3.1). Snow (1979a) believes that cognitive tests which incorporate a learning component could be used to measure the ability of the individual to adapt his procedural assemblies and strategies to changing task demands. Even crystallized production systems should not be assembled in an inflexible way; they should have the plasticity to enable modifications or extensions to be done when needed.

Sternberg (1982) states that reasoning may be characterised as an attempt to combine elements of old information with new information. In the process of solving a problem, an individual draws relevant information from his memory stores and places it in his working memory along with the information which is given in the task instructions. In problems which have been encountered frequently before, the process of integrating these two sources of information and executing a solution procedure may be straightforward. For instance, when given two numbers and asked to add them, most individuals simply recall their addition "program" from memory and "plug in" the numbers which were given in the problem. Some problems, however, especially those which have not been encountered before, require novel integrations of stored and new information, and may require the modification of crystallized "off the shelf" programs, or even (in extreme cases) the compilation of a new program. It is problems of this sort which require cognitive flexibility on the part of the problem solver.

In terms of Minsky's (1974) frame model, cognitive flexibility involves the ability to change parameter defaults swiftly when the occasion demands. Flexibility also involves the ability to select the appropriate frame (schema) for the context or to change frames if this is likely to facilitate the execution of the task (Polson and Jeffries, 1985). Another way of saying this is that the individual should be able to select a representation of the problem in which fairly direct solution paths exist.

In some tasks (e.g., in certain psychological tests) the individual has to make frequent frame changes in order to perform effectively. Each subtask (e.g., item) may look superficially quite similar to others but require a different strategy or procedure to solve it. It is in such cases where cognitive flexibility is essential to effective performance. Through the judicious selection and ordering of subtasks it should be possible to devise a method to study flexibility-rigidity at the process level.

4.0 NEW DIRECTIONS IN ASSESSMENT

In the previous two chapters our concern was not with tests as such, but rather with topics which may have relevance for the development of new types of assessment instruments. In this chapter we shall focus directly on the implications which these topics have for the development of novel testing approaches. The importance of these approaches does not rest on their novelty per se, but rather on their potential to assess aspects of human functioning which were previously inaccessible.

Chapter 3 was long and covered a wide field. In order to orientate ourselves, we shall itemize some of the major themes which may have implications for assessment.

4.1 MAJOR THEMES

1. As psychological constructs, factors are largely meaningless because they give no insight into the operations which are required in order to do a given task. Two tests which load on the same factor place certain common processing demands on the subject, but each usually also imposes certain processing demands not imposed by the other. It is therefore not justifiable to say that two tests which load on a given factor are equivalent in terms of processing requirements. In addition, common and unique processing demands cannot be inferred from knowledge of the factor structure of tests.

2. Conventional tests (generally speaking, those based on a factorial model) are moderately successful at predicting gross criteria (such as performance on a training course). They cannot, however, be used to determine why certain individuals fail to achieve success on a criterion or how training could be modified to improve an individual's chances of success.

3. "Micro level" information processes tend to be rather task-specific. Consequently, it is difficult to generate general theories using these constructs. Metaprocesses are higher-level constructs which are less task-specific. Metaprocesses, or cognitive strategies, have a major impact on task efficiency. Hence very useful information on cognitive processing can be obtained by measuring differences in the application of metaprocesses.

4. There are many sources of individual differences in information processing, including choice of processes, order of applying processes, time taken doing each process, etc.

5. Cultural factors have a major influence on the way in which information is processed in order to achieve a given goal. Researchers must guard against cultural bias when determining which processes are needed to do a particular task and how these processes should be applied to do the task optimally. The main purpose of cognitive psychology should be to study differences, not impose

general models which might be appropriate for the cognitive functioning of only certain people (e.g., those who belong to the dominant culture in a society).

6. Education should aim, as far as is possible, to adapt its mode of presentation to the processing styles and strategies of learners. For this reason it is necessary to know how different individuals process information (appropriate measures are therefore required). Only when there are definite lacunae in an individual's armoury of processing tools, should strategies be taught. Educationalists should not try to force all individuals to process information in the same way. Remediation should be undertaken when a person lacks necessary and general processing skills (see Sternberg's, 1986a, description of these concepts, discussed in section 3.3).

7. Cognitive psychology, educational psychology, and psychometrics should be brought together in an information processing paradigm. All three disciplines will benefit from their association with one another. The benefits for cognitive psychology include the following: More can be learned about the dynamics of information processing if learning is included in the research design; and more attention can be paid to individual differences in experimental research if psychometrics is given a place in such research. The benefits for psychometrics are: Test construction can be more theory based; the exact content of tests can be more rigorously controlled; and it will become possible to devise measures of individual differences in processing information. For educational psychology the benefits include: The development of cognitively-based theories of instruction; and the development of diagnostic testing and adaptive educational procedures.

8. The ATI (aptitude-treatment-interaction) model has been used mainly to identify optimal instructional modes for pupils at different ability levels, although the model does not preclude the inclusion of other types of treatment, such as different types of task, in place of different modes of instruction. In its conventional form, the ATI model is "crude" in that ability is assessed in a global fashion which gives no insights into styles or strategies of task execution. Instructional modes are also differentiated from one another only in a gross fashion. A combination of information processing theory and ATI might eventually lead to a model which can be used to study information processing dynamically in a teaching/learning context.

9. There are various types of information processing approaches. Among these are the cognitive components approach, the cognitive correlates approach, and the cognitive contents approach. The cognitive components approach is not a very suitable vehicle for individual differences measurement and is better suited to experimental designs. The cognitive correlates approach is concerned with determining the processing differences between good and poor performers on given tasks. Although group (rather than individual) differences are studied in this approach, the information gained about group differences can be used to develop individual differences measures. The drawback of this approach is that the tasks which are

generally selected for study are conventional tests. As the purpose of psychometrically orientated information processing research should be to replace conventional tests with process-based ones, the choice of conventional tests as tasks for study is open to question: The cognitive correlates approach seems to be a hybrid which incorporates elements from "old time" factorially-based psychometrics and modern information processing theory. The cognitive contents approach appears to offer the best prospects for the development of process-based individual difference measures. It is similar to the cognitive correlates approach in that it addresses itself to finding process differences between good and poor performers, but it concentrates on real-life tasks. It is also more orientated to the study of learning phenomena and developing models of knowledge acquisition. The cognitive contents approach can be designed to include repeated measures, so that learning curves over blocks of items or instructional modules can be obtained.

10. One of the ways in which it may be possible to determine the processing differences between good and poor task performance is through the use of faceted tests. In faceted tests, items are made up of characteristics drawn from various dimensions (facets) which are relevant to the content area. The facets are "crossed" with one another to produce a universe of items with precisely defined content. Faceted tests can be used in an extended ATI model; in such a model, a faceted test replaces the conventional criterion measure. The ATI model then becomes an Aptitude X Treatment X Facet Interaction model (an "ATFI" model). Comparing performance on items with different facet content can give clues as to what processes were used by the subject.

11. The ATFI model still includes a global aptitude measure (the "A" in the acronym). A further development of the model could be undertaken which would involve the replacement of this global measure with a more process-orientated one. (A model which includes a faceted test at both "ends" is proposed in the next chapter.)

12. In order to develop process based testing-teaching-testing models it is necessary to perform task analyses on the instructional material. There are several shortcomings to conventional task analysis. Some of these are overcome in Genetic Task Analysis.

13. Problem solving is a useful vehicle for the study of information processing. The use of the computer as the mode of presentation makes it possible to devise ways of "tracking" the cognitive steps taken by the subject in the solution of the problem.

14. There is a trend away from studying human performance in knowledge-poor domains and towards investigating knowledge acquisition and task performance in knowledge-rich content areas. Where previously knowledge was regarded as irrelevant and a hindrance to the study of "pure" reasoning, the study of knowledge acquisition and representation is now regarded as important in its own right; in a turn of the tables, reasoning in knowledge-poor domains is increasingly regarded as being too trivial to warrant much research.

Consequently, there is increasing interest in problem solving in domains with large problem spaces or with large amounts of interrelated information. In some studies, real-life domains (e.g., school curricula) are used, in others complex laboratory tasks. The former has the advantage of being "for real", while the latter enables stricter control to be exercised.

15. The study of styles or strategies of information processing should be complemented by research into knowledge representation, and changes in representation as a result of learning or experience. A number of models of knowledge storage exist, including hierarchical, categorical, dimensional, and schema-based models. One or more of these could be used as the basis for research into knowledge structure. When information processes are inaccessible to the researcher, structure of knowledge can be used to give an indication of what processes were probably used. Structure of knowledge is like the pattern of iron filings on a sheet of paper after a magnet has been applied to the underside of the paper: It is a semi-permanent trace of dynamic events. Knowledge structures are important not only because they are a second-hand way of inferring information processes. They are also important because they are a reflection of intelligence. There are more and less intelligent ways of storing information for use within a given context.

16. There is a growing body of opinion that cognitive competence is modifiable. Conventional tests measure achievement level which the person achieves without the benefit of any kind of intervention or coaching. The degree to which an individual's level of performance under these conditions can be improved is known as his zone of proximal development (ZPD). ZPD appears not to be highly correlated with conventional ability scores. In countries where some groups are considerably more advantaged than others, ZPD might prove to be a fairer index of potential than conventional test scores. Conventional tests measure not only ability but also advantagement; this is demonstrated by the correlations normally found between scores based on these tests scores and SES.

17. ZPD has been used by Feuerstein (1980) to determine the degree to which an individual is likely to benefit from mediated learning experiences. Feuerstein employs conventional tests in a non-standard fashion, to isolate cognitive deficits. A "Cognitive Map" guides the investigator in this procedure. Mediations are then undertaken to remove the cause of cognitive deficits. Feuerstein's contribution is that he has devised a complete "package" of diagnosis and remediation. His diagnostic tools are, however, informal and clinical, hence not practicable to apply to large numbers of individuals in educational or industrial settings. A further problem is that the Feuerstein diagnostic approach is not thoroughly process-based.

18. Transfer is a construct which is quite closely related to ZPD. Transfer seems to differ from ZPD in that it indicates the capacity to use acquired skills in new applications; ZPD on the other hand reflects improvement, after intervention, in the same domain.

Transfer is regarded as a very important aspect of intelligent behaviour. Learning-deficient and retarded individuals show particular weaknesses in their ability to transfer learning from one context to another. Transfer is affected by the way knowledge is stored. More abstractly stored knowledge is likely to be transferred more easily. Also, knowledge has to be stored in a complete form in order to be transferable; this is important because most instruction is incomplete and the learner is required to "fill in the gaps." To the author's knowledge, no pure measures of transfer exist.

19. Cognitive functioning cannot be studied in a way which completely ignores non-cognitive phenomena. Styles are broad approaches to processing information which reflect, or are influenced by, certain characteristics in the "grey area" between personality and cognition. Impulsivity and cognitive rigidity appear to be the most important of these, at least from the point of view of effectiveness of performance. Poor performance can result from impulsive or rigid styles. Conventional tests cannot be used to distinguish between poor performance for these reasons or poor performance due to other limitations (e.g., limitations in abstract reasoning ability). Individuals can be taught to use styles which are more likely to lead to success. An impulsive style can be eliminated or moderated by teaching an individual to spend more time planning and considering options before engaging in behaviour.

4.2 POSSIBLE NEW APPROACHES TO ASSESSMENT

In this section we will discuss some of the possible new directions for assessment.

Assessment of metacognition

Metacognition exercises an executive function in the processing of information. Lack of metacognitive control can be likened to lack of managerial control in an organization: In both cases resources are not likely to be used effectively in the performance of the tasks in hand. Most conventional tests place demands on the testee's metacognitive skills, but the scores derived from such tests are not pure measures of these metacognitive skills.

A number of metacognitive processes have been mentioned by information processing theorists. These include:

1 Recognizing that a problem exists
2 Exhaustively examining the stimulus material
3 Assembling all relevant information in working memory
4 Selecting a representation for a problem
5 Being analytic -- breaking the task down into subgoals
6 Planning the task execution strategy
7 Allocating processing resources
8 Monitoring the effectiveness of the steps taken
9 Testing one's strategy as one performs it
10 Revising one's strategy as the need arises

11 Evaluating the strategy for effectiveness
12 Storing information in such a way as to facilitate transfer to related tasks in the future.

Sternberg (1986a) states that he is developing a battery of tests intended to measure directly certain metacognitive abilities. This battery is apparently of the pencil-and-paper variety.

It seems to the present author that metacognition could be assessed more effectively using the computer as a mode of presentation. Computer administration has at least two advantages, both resulting from the fact that the individual can be monitored in real time. The first advantage is that it is possible to measure the amount of time which an individual spends on various tasks, such as examining the stimulus material and planning his strategy. The second is that testing programs can be designed which require the subject to externalize his processing steps. For instance, he may have to "ask" the computer to perform some activity in order to monitor the effectiveness of his strategy; a record will then be made of the fact that he used Metaprocess 8 (see above) at a given point in the execution of the task. Problem solving exercises may prove to be the best vehicle to study metaprocessing.

The order in which certain processes or metaprocesses are executed may be just as important as whether a given process or metaprocess is used. Both of these give the investigator valuable insights into how the individual processes information. As we have discussed earlier, strategies are likely to differ markedly from group to group in a multicultural society such as that found in South Africa. It should be possible to design tasks which make it possible, through the use of a computer, to evaluate not only whether a metaprocess was used, but also in what order a set of metaprocesses were used.

Faceted tests

The construction of test items has traditionally been a more-or-less intuitive activity. This is largely because the item constructor is required to work from a very vague and general definition of the content area; definitions of this type are the inevitable result of research done at the factorial level.

One of our major criticisms of conventional ability tests in this report has been that the processing demands placed on subjects doing such tests is unknown. Many tests are composed of a variety of different types of items which require the application of different sets of processes. A high score on a test of this kind indicates that the testee was able to marshal most of the processes and metaprocesses required to answer the items. A low score indicates that much processing was done inadequately, but the score does not indicate where the testee's processing is inadequate.

Construction of items according to a faceted design can help to overcome this problem to a large extent. Guttman and Schlesinger (1966) state (p. 3): "Given any two sets of elements A and B which we call facets, their Cartesian space is the set of all pairs of elements ab where a is an element of A and b is an element of B. A Cartesian space may consist of any number of facets, or sets of elements; with n facets, any one point in the Cartesian space has n component elements." Guttman and Schlesinger list three advantages of using a facet approach in test construction:

1. Items and distractors can be constructed in a systematic way.

2. The possibility of revealing empirical relationships between items and tests is enhanced.

3. A parsimonious and efficient use of the test items in the prediction of external criteria is possible.

Facet theory was developed before information processing theory became a major trend in cognitive psychology. None of these advantages is directly relevant to information processing theory and research. However, the control over item content which can be achieved through the use of a faceted approach can assist the cognitive psychologist to infer cognitive processes. Clearly the technique has diagnostic potential since performance on a number of defined tasks can be compared. The aim of the processing psychologist should be to develop the faceted approach to enable him to make diagnoses about processes. In the conventional application of faceted test construction, the selection of facets and elements of facets is not done with processing issues in mind. If faceted tests are to be constructed which can be used to make diagnoses about processes, information processing theory will have to be used to identify the facets or dimensions of interest.

It seems unlikely that faceted testing will permit direct assessments of processes to be made. Faceted tests, like their conventional counterparts, are designed to measure products, not processes; the advantage which faceted tests have is that fine-grained information can be collected which can be used to infer what processes were probably used.

Faceted testing can be used on its own, but its most powerful application is likely to be in the context of extended ATI models (see points 10 and 11 in the previous section). In ATI-based applications, faceted testing can be used to track changes in processing as a result of different types of instructional inputs. Two types of information could be obtained from designs of this nature: Diagnosis of processing strategies and deficits, and identification of optimal instructional techniques for different purposes.

Measures of structure of knowledge

Conventional achievement tests do not measure the structure of the subject's knowledge; they do not permit the assessment of how information is interconnected, only of how much knowledge an individual has in a given domain. In a conventional test, each item is independent of other items and the items as a whole are supposed to represent a sampling of the content domain in question. The individual's knowledge is represented by a single score which is the sum of his correct answers. As this sum is derived from responses to items which are unrelated to one another, little or nothing is learned from this score about how the individual relates items of knowledge to one another.

The assessment of knowledge structure has implications for diagnosis. Diagnostic assessments can be performed on procedural or declarative knowledge (see section 3.2), although our emphasis here is mainly on declarative knowledge. Assessments can be performed for two purposes: To determine what type of knowledge structures an individual has, or to ascertain where and how his knowledge network fails to conform with an "ideal" network (or with an expert's network). The former can be used to devise adaptive instruction to capitalize on existing structures (genetic task analysis could be used for this purpose); the latter can be used to plan a remediation aimed at correcting misconceptions of both a factual and relational nature.

Several experimental measures have been designed to assess knowledge representation (see for instance de Jong & Ferguson-Hessler's, 1986, technique which is described in section 3.2). At present most cognitive psychologists interested in knowledge representation are employing concept categorization techniques (which require the subject to place concepts in different "piles"). Unfortunately these methods produce a rather rudimentary representation of knowledge structure. Ultimately computer-adaptive instruments which incorporate a degree of artificial intelligence are likely to supplant these more basic techniques. An "intelligent" assessment technique will use hypothetico-deductive methods to develop a model of the individual's cognitive structures; his performance on a set of introductory tasks will be used to develop hypotheses about cognitive structures or deficits, and these hypotheses will be tested by presenting the individual with tasks specifically designed to test the hypotheses.

Willcox (1983) developed a diagnostic testing procedure for addition and subtraction which can indicate the probability that the subject is using each of a number of incorrect strategies. Seeley-Brown and Burton (1978) devised a model for representing arithmetic which permits both correct as well as incorrect procedures to be represented. Seeley-Brown and Burton point out that representations must be of such a type as to make it possible to go from surface errors to "deep structure" representations of these. In a computer aided instruction (CAI) context, such techniques could be used to perform swift "trouble shooting", followed by remedial educational inputs aimed directly at the problem. This type of intervention could be applied on an ongoing basis during instruction.

Error analysis

In error analysis the aim is to arrive at a diagnosis of deficits from an analysis of the incorrect answers which an individual gives in a test. Unlike the knowledge representation approach, the error analysis approach often makes use of reasonably conventional measurement instruments (this situation might change as error analysis becomes more sophisticated). In conventional testing, little attention is paid to errors save to count the number of these. In error analysis, on the other hand, the type and pattern of errors form the basic data of the analysis.

According to Bejar (1984), error analysis has been used mainly by content specialists rather than psychometricians. For example the Monroe Diagnostic Reading Examination classifies errors into categories such as "faulty vowels", "reversals", and "omissions of sounds" (Spache, 1976). The problem with this approach is that it aims at forming inventories of error types but does not address itself to underlying processing deficits.

Thissen (1976) gave 570 high school students items from the Raven Progressive Matrices. The data were analyzed using a maximum likelihood approach in which estimates of ability were based either on right-wrong scoring or on the pattern of wrong and right responses. The author found that information was present in the wrong responses which could be used to improve the ability estimate. He claims that improvements in ability estimates are likely to result when item distractors have been generated according to some theory. In order to learn about process deficits from an approach such as that described above, it is necessary that the theory used to generate distractors be of a process type.

Tatsuoka and Tatsuoka (1982) introduce two indices of consistency. The first, Norm Conformity Index (NCI), indicates the extent to which the pattern of wrong and right answers in a test approximates a Guttman matrix. If items in the test are ordered in difficulty according to some criterion, then one would expect "all the ones to be to the left of the zeroes": Each person should answer all items correctly up to a certain point (determined by his ability level) after which all items should be answered incorrectly. In practice this almost never happens, but it is possible to quantify the degree to which a perfect Guttman matrix has been obtained. The NCI is a quantification of the degree to which a particular group's responses approximate the Guttman matrix. According to Tatsuoka and Tatsuoka, groups with different cultural or educational histories may have very different NCIs even when their mean scores are similar. Presumably this information could be used for diagnostic purposes, although the authors do not clearly spell out how this could be done.

The second index which Tatsuoka and Tatsuoka (1982) introduce is Individual Conformity Index (ICI). This index is a measure of the degree to which an individual's pattern of responses remains consistent over time (e.g., over a series of parallel tests). The authors hypothesize that when an individual is in the process of learning he will modify his cognitive processes frequently as he attempts to solve problems; his pattern of responses on successive sets of problems of a similar nature will be expected to change considerably from one set to the next. On the other hand, when the individual approaches a learning plateau, his response pattern will stabilize. ICI could therefore be used to determine the individual's likely position on his learning curve. Having a high test score combined with a high ICI is probably the most favourable situation because it indicates that already high competence is likely to become higher. The combination of a low test score combined and a high ICI is probably the worst situation as this indicates that the individual is perseverating on erroneous strategies.

Error analysis does seem to have some diagnostic value, but the approach in its present form stops short of giving useful information at the processing level. ICI combined with an achievement score gives an indication of the consistency and effectiveness of an individual's strategy usage in problem solving, but it does not give the investigator information on actual strategy usage.

Error analysis, in its present form could possibly be used in conjunction with one of the other methods which are more effective at determining strategy usage. More sophisticated forms of error analysis might ultimately be developed which use "active" techniques to determine the types of errors which an individual makes in the process of doing a given task. This approach might be quite similar to the hypothetico-deductive approach mentioned in the previous subsection. The difference between the two lies in their aims: In the application mentioned in the previous subsection, the purpose was to assess deficits in declarative knowledge whereas in the application mentioned here, the purpose is to assess deficits in procedural knowledge.

Learning potential and transfer

Learning potential is also known as modifiability and zone of proximal development. This construct appears to be particularly relevant to education, as learning potential scores should be predictive of performance in an educational context. These scores should be especially useful when the educational institution offers bridging courses (as some universities do) and wishes to determine which students are likely to benefit most from such "remedial" education.

Learning potential measures have three sections:

1. An initial assessment of performance in the content area
2. An intervention or lesson of some kind which is intended to teach some of the core concepts or procedures required for effective performance in the area
3. A second assessment of competence in the area.

The assessment instruments for the pre- and post-tests should be designed in such a way as to make a meaningful difference score possible. Ideally, pre-test and post-test items should be matched. A latent trait model can be used to do this (Embretson, 1985). An alternative approach is to use highly structured material such as Kotovsky and Simon's (1973) letter series. The difficulty level of these series can be determined using a formula which has proved to

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give results which are very highly correlated with empirical results. Any Kotovsky-Simon type series can be expressed in rule form, and this rule can be used to generate an almost infinite number of equivalent series. Hence it is possible to have precisely matched items in the pre- and post-tests.

Various indices can be used to assess the change in competence after the instructional intervention. These include differences between pre-test and post-test performance in: Number of errors made on the test; number of attempts at each item; time taken to do each item; and number of hints needed to do a particular item (usually, increasingly direct hints are given after each failure to do an item). The most commonly used methods are number of errors on the test and number of hints. For mass (pencil-and-paper) testing, the only viable method is number of errors. More sophisticated evaluations can be done in computerized testing.

The most common practice in learning potential evaluation is to use some sort of novel reasoning task as the content domain; areas which may be more familiar to some subjects than to others (due to differences in education or other life experiences) are generally to be avoided. Three kinds of information can be imparted in the intervention stage: The teaching of (1) "facts", (2) procedures (production systems), and (3) metaprocesses. To date, very little attention has been paid to the design of instructional material in learning potential assessment; information intended to improve performance is included but the nature of this material is not carefully analyzed. The intervention should be designed with the goal of the assessment in mind. In many practical applications (such as selecting individuals for a bridging course) it may be desirable to teach only facts and procedures, because the bridging course will address itself to teaching only facts and procedures, and one may want to match the two instructional interventions as closely as possible. If an individual has metacognitive deficits, these will be common to the testing situation, the bridging course, and the actual course for which the bridging course is a preparation. On the other hand, in settings where more thoroughgoing and personalized remediation is possible, it becomes desirable to include measures of metacognitive skills in the assessment instrument and to teach lacking metacognitive skills in the intervention phase. Such an approach is less standardized but may give the investigator a more sensitive indication of the individual's educability and the sort of remediation which he requires.

One of the difficulties of measuring learning potential is that difference scores are notoriously unreliable. Both pre-test and post-test should therefore be as reliable as possible to reduce this problem. As reliability generally increases with test length, it is likely that the pre-test and post-test will be rather long if the difference score is to be reasonably reliable. Another option is to use adaptive tests which can be made to reach a given level of reliability with fewer items. A disadvantage of this approach is that each individual receives a different subset of items. Doing the pre-test and post-test items is part of the learning experience in a learning potential assessment. If different individuals receive different items, then the learning opportunities are not standardized. A further problem with this approach is that the pre-test and post-test are unlikely to be perfectly matched.

Another problem which has not yet been properly addressed concerns ceiling effects. Individuals who score well on the initial test have less "room for improvement" than low scorers, especially if the second test is the same length as the first. One solution is to have "topless tests", i.e., tests which for practical purposes have no upper bound because a number of very difficult items are included at the end. The disadvantage is that many testees may be intimidated by this. The problem is done away with if the tests are adaptive, but the reservations about adaptive testing noted above should be borne in mind.

Transfer is related to learning potential, but is usually measured as a separate entity. The items of a learning potential pre-test are highly comparable with those of the post-test; this is usually not true in transfer exercises. Transfer items differ on one or more characteristics from the items which were encountered in the pre-test and instructional phase. In "near transfer" items, the differences are small, whereas in "far transfer" items, the differences are large. No effective way has yet been developed of quantifying the degree of transfer in an accurate manner. Usually different sets of items are devised which are designated "near transfer", "far transfer", and "very far transfer"; an individual's performance on each of these sets is then assessed. Although this approach gives the investigator some idea of the degree to which the person can transfer learning, the amount or extent of transfer cannot be quantified as accurately as learning potential. (How much does "near" differ from "far" and "very far"?) Transfer assessment of the kind mentioned above is adequate for experimental research, but more sophisticated techniques are needed for individual differences measurement. Methodological developments might ultimately eliminate these measurement problems.

The assessment of information processing styles

In section 3.5 we discussed the effect on information processing of variables in the "grey" area between affect and cognition. Two variables were singled out for special attention: Impulsivity and cognitive rigidity. It was mentioned in section 3.5 that these two constructs could be regarded as affectively based styles of processing information. Styles are broader and more general than metaprocesses.

Impulsivity is usually assessed using the MFFT (which was described in section 3.5). This test is more suited to experimental than to individual differences applications because it is basically a classification instrument. Further problems are that classification is sample-based and that not all individuals are classified into the impulsive and reflective categories. Some other technique of measuring individual differences in impulsivity is therefore required.

Impulsivity has an impact on many types of metaprocesses. An impulsive problem solving style is sufficiently pervasive that it will leave its characteristic "mark" on the way a number of metaprocesses are executed; in some cases, an impulsive style will result in some types of metaprocesses not being activated. Let us be more specific. Consider the metaprocesses listed in the subsection above entitled "Assessment of metacognition". The impulsive problem solver is not likely to examine the stimulus material exhaustively (Metaprocess 2), nor to assemble all relevant information in working memory (Metaprocess 3); he is also unlikely to spend enough time planning his strategy (Metaprocess 6) and evaluating his strategy for effectiveness (Metaprocess 11); in addition, he is unlikely to take the trouble to store his experiences of the problem in such a way as to facilitate transfer to other related problems (Metaprocess 12).

A rigid cognitive style will also be detectable from the way certain metaprocesses are executed. A rigid problem solver is likely to experience difficulty in finding an appropriate representation for a new problem type which differs from those recently encountered (Metaprocess 4); he is also likely to experience difficulty in revising a strategy which is not working properly (Metaprocess 10).

It seems then that impulsivity and cognitive rigidity are manifest in certain "syndromes" of metaprocessing. It should be possible to devise tasks (administered by computer) which involve all the metaprocesses mentioned above. Impulsive and rigid styles of processing could be detected quite easily, possibly through the use of normative comparisons.

4.3 SUMMARY

In the previous section we investigated six new types of measurement approaches: Assessment of metacognition; detection of different types of processing through the use of faceted tests; assessment of structure of knowledge; error analysis; assessment of learning potential and transfer; and measurement of certain stylistic processing variables.

Let us consider some of the major similarities and differences among these approaches. Some of the approaches include instruction and learning as an integral part of the procedure whereas others need not have this component. Learning potential assessment and faceted testing (used in the context of an ATI-type model) both include an instructional component. The other approaches listed above can be used without an instructional component, but extra information is obtained if changes are monitored as a result of learning. For instance, changes in the structure of knowledge as a result of learning is more interesting and informative than a single "snapshot" of knowledge structure at a specific time.

The approaches also differ on the "grossness" or "fineness" of the information which is obtained. The information obtained from a conventional learning potential assessment instrument is fairly gross:

a single score summarizes the change in performance. At the other extreme, the use of multi-faceted measures to determine performance differences after the administration of various types of instruction (which differ from one another in precisely defined ways) yields information of a very fine-grained nature. The information obtained by monitoring strategy or metaprocess usage is at an intermediate level of fineness. (Some of the information which could be obtained on metaprocesses includes: Which metaprocesses are used, in what order they are used, how efficiently they are used, and how much time is spent executing each.)

Information is not automatically more useful or informative just because it is more detailed. One must bear in mind the purpose for which the assessment is being performed. For the purpose of selecting individuals for certain types of training, the "gross" information obtained from a learning potential test might be more useful than a mass of information obtained from a multi-faceted test.

Tests are usually used for selection, but there are at least two other uses for the assessment techniques which were described in this chapter: Remediation/adaptation, and basic research into information processing and educational issues. We shall deal with these three applications separately.

Many tests already exist for selection. Conventional tests have been used for many years as an aid in making selection decisions for jobs and training courses. Learning potential measures add to the list of selection instruments and enable the investigator to obtain information about an individual which would not otherwise be available. Learning potential is particularly relevant when selection is for activities which involve a significant amount of learning. Training courses and jobs in which the individual will have to learn are examples of these kinds of activities.

From the above discussion it should not be concluded that selection is the only use for learning potential tests; they also have their uses in clinical and experimental settings.

The purpose of using tests for remediation or adaptation is to monitor an individual's performance so that the educational material can be adjusted in order to improve his performance (see comments made elsewhere in this report on remediation and adaptive education). The educator requires information from tests which can guide him in the selection or design of adaptive or remedial material. In other words, tests must give information which is easily "translatable" into educational terms.

The effectiveness of computer aided instruction can be increased dramatically if computerized diagnostic assessments are included in the overall "package". Results of these assessments direct the course of instruction to be optimally beneficial to the individual. The individual is "branched" to material appropriate to him at his present point in the learning process. Clearly, testing and education have to be highly integrated if information from testing is to be fed into a computer program to direct the course of instruction in an optimal way.

Assessment of metaprocessing, structure of knowledge, affective style (impulsivity and rigidity), and error analysis could be used for the purposes of remediation and adaptive education.

In basic research into information processing and educational issues, highly controlled and structured designs are used. This should be contrasted with the lack of standardization in adaptive education and remediation, where assessments are applied at regular intervals and used to select or adapt educational material to the current needs of the individual. In basic research, the aim is not to "help" but to "learn"; procedures are standardized and instruments are designed to answer particular research questions. These instruments may not be practically useful but the research findings which flow from the use of such instruments may ultimately lead to practically usable assessment techniques. Process-based variants of ATI models may be particularly suited to experimental and basic research applications.

The above discussion was not intended to "pigeon-hole" assessment techniques into different application categories, but to give some idea of where and how the new techniques could be used. It is possible that all the methods could be used for all three applications mentioned above, but some methods may be more suitable for one application rather than another.

5.0 CONCLUSION: NEEDS AND PROSPECTS

South Africa is one of the most multicultural countries in the world. In some respects it belongs to the First World while in others it belongs to the Third World. Business in the large industrialized centres is run on First World lines, but many of the workers are from a Third World cultural background. Another factor which adds to the heterogeneity of the country is the variance in levels and quality of education. There are significant numbers of people at all levels of education; this contrasts with the situation in developed countries, where very few adults have only a primary school education and almost no-one has no education at all. The different educational systems in Southern Africa offer different qualities of education ranging from very good to poor. In some schools, pupils are taught to generalize beyond the immediate problem, while in others, "parrot" learning is encouraged.

Employers, who generally come from a First World background and who have had an education commensurate with this background, are often dismayed by what they see as the lack of effective work skills in the labour pool from which they draw their staff. Employees from a Third World background, on the other hand are liable to find the work environment and work demands foreign and unpleasant.

The usual response on the part of employers is to blame inefficiencies at work on skill deficits in workers. This is partly justified: Skill deficits are likely to result from inferior quality education; also, skills required in one culture might not be taught or exercised in another culture. It is, however, paternalistic and culturally chauvinistic to claim that all incompatibilities between peoples' skills and the task demands of First World Industry should be rectified in all cases by changing people rather than changing the nature of tasks. Adaptation is required on both sides. Industry should adapt the nature of tasks to the predominant styles of information processing of the workforce, to the extent that work efficiency is not seriously affected. On the other hand, adaptation of workers to the demands of the industrial world is also required, as there are constraints on the modifiability of the work environment.

These two types of adaptation (of organization and of individual) in the workplace are analogous to the two types of adaptation which we have been discussing in the educational sphere: Adaptive education and remediation. The former involves changing the nature of tasks to suit the individual and the latter changing individuals to suit the tasks. In all societies it is important that both types of adaptation occur, but in a multicultural society such as South Africa's, adaptation and compromise are required to a greater extent.

In order to achieve this aim in the work and educational spheres, it is necessary to know about the characteristics which make groups or individuals different. In particular, we need to know more about the thought processes of people, so that education can optimally benefit them and so that skills and work demands can be matched. Conventional assessment techniques are not equal to this task because they give only a gross picture of an individual's skills. These techniques measure how many problems in a given domain a person does correctly, not how he went about trying to do them. In other words, conventional tests are not diagnostic. Many people in South Africa who have been reared in one culture (an indigenous one) are attempting to be competent in another (the Western one). Diagnostic assessment techniques are required to determine how such people are going about this, so that adaptation and remediation can be effected.

Diagnostic instruments can only be useful if they are diagnostic at the cognitive process level. Most existing tests which are called diagnostic diagnose problems only at a superficial level. Such measures assist the educator to determine deficits specific to tasks in a given content domain, but not to identify underlying processing deficits which will be manifest in many content domains.

We have stressed in this report the importance of integrating instruction and assessment within an information processing paradigm. We have also stressed the importance of studying performance on real-life tasks rather than on artificial or laboratory tasks. It will be remembered from section 3.1 that three information processing approaches were described: The cognitive components approach, the cognitive correlates approach, and the cognitive contents approach. It was stated that the cognitive contents approach appeared to be the most useful for our purposes. The main aim of this approach is to find the processing differences between good and poor performers on real-life tasks.

Learning can be studied in the cognitive contents approach, either the learning which results from formal instruction or that which results from experience "on the task". Cognitive contents research which incorporates a learning component addresses itself to determining the processing differences between good and poor learners and to investigating the effects of different types of instruction on information processing. The cognitive contents approach is therefore a suitable vehicle to achieve the aims of integrating education, testing, and cognitive psychology, and studying performance on content-rich real-life tasks.

This approach can accommodate both theoretical research and practical applications. Theoretical investigations into cognition and education can be performed in the cognitive contents approach and these findings can lead to the development of practical "tools" such as diagnostic assessment instruments and instructional techniques adapted to the learner.

In the previous chapter we discussed six new directions in assessment which could lead to process-based instruments. All of these can be used in the cognitive contents paradigm, particularly the following: Assessment of metacognition, ATI-based faceted testing, and assessment of structure of knowledge. Let us consider each of these in turn.

From our previous discussion it is clear that high-level cognitive control functions (metacomponents, metacognitions, or strategies) have a very important influence on the effectiveness of task execution. We include learning under task execution, because learning is in effect a task. The metacognitions which come into play in learning may not be entirely the same as those which are used in problem solving, but there is likely to be a substantial domain of overlap between the two sets of metacognitions. Learning usually precedes task execution or problem solving. Strategy use in problem solving is largely a function of previous experience with related problems. In many basic research exercises, previous experience is an unwanted and difficult-to-control factor. Its influence can be reduced radically by teaching subjects a new content area "from scratch". The advantage of this from the point of view of information processing research is that the use of strategies can be studied ab initio and as learning progresses; both knowledge acquisition and problem solving (doing exercises based on the material which is being taught) can be studied in this way.

Research such as that sketched above requires computer-based administration procedures. The test constructor has to exercise his ingenuity to devise ways of externalizing the metacognitive processes which the individual engages in in the process of doing the task. One way of doing this is to have a "main menu" of relevant metacognitions. In order to execute one of these metacognitions, the individual will have to ask for it, and this will be recorded by the computer.

Not all metaprocesses can be externalized this way. For instance, Metaprocess 12, which concerns the storage of information (see section 4.2), might best be investigated differently, by testing the individual's performance on various tasks which require him to transfer his learning. Some metaprocesses may be too elusive to externalize, but many can be investigated using techniques such as those described above.

The assessment of metaprocessing is probably most easily done in the context of problem solving, rather than learning, although, as we have noted above, metacognition is just as important in knowledge acquisition as it is in problem solving. If the main interest is in the individual's learning in response to different kinds of instruction, then some sort of ATI design is required. We have discussed the shortcomings of the conventional design, but also suggested that it can be modified in a number of ways to make it more suitable for research which is process-orientated. Modifications can be introduced in three places in the design: In the initial assessment of skills or competence, in the analysis and design of the instructional phase, and in the post-instructional evaluation of skills or competence.

It is in the post-instructional evaluation that faceted testing is most relevant. The purpose of faceting is to find clues as to how information is processed by comparing performance in various "cells" of the space defined by the facets or dimensions. The choice of dimensions and points on the dimensions which are used to generate items should be selected to facilitate this sleuthing process.

The faceted design can be embedded in a larger ATI design. There may be several types of instruction as well as several groups of individuals incorporated in the design. Fairly complex analysis of variance techniques are required to analyze the data rigorously; the design permits the investigation, in an integrated fashion, of the effects of different types of instruction on the information processing of different categories of learners. A problem which remains to be solved is to devise some way of controlling for item difficulty in order to make cells, columns, or "planes" of item scores strictly comparable.

In section 3.2 a number of models of knowledge representation were discussed. Models can be classified according to the principle or principles used to relate memorial elements to one another. Four types of models were identified in section 3.2: Hierarchical, network, schematic, and dimensional.

Several researchers have attempted to assess structure of knowledge through the degree of overlap between the individual's cognitive structure and some ideal structure. This research has been based on hierarchical and dimensional models of memory structure. Degree of overlap is only one way of describing structure, and a very gross one at that. Other indices should be developed which are sensitive to specific changes in structure as a result of learning or experience. Different models may be suitable for studying different characteristics of memory structure. Under the schematic model of knowledge representation, for instance, one can assess changes in default assignments and linkages between frames. Dimensional models allow one to study the "projections" which individuals perform in order to generate a context for use in a particular task. Ultimately some sort of overarching theory will have to be created which will integrate the models of knowledge structure and facilitate research in this area.

There are at least two reasons for developing methodologies to measure knowledge structure. One is to monitor changes in the structure of knowledge as a result of learning. The second is to assist the investigator in inferring characteristics of the individual's strategies of information processing. In an instructional context, monitoring change in knowledge structure permits the investigator to assess the impact of the instruction. The acquisition of both declarative and procedural knowledge can be studied in this way. If sensitive and fine-grained indices of structure are available, these can be used to remediate misconceptions or lacunae in knowledge, or to adapt education to capitalize on existing knowledge structures.

We have selected three new measurement approaches for special attention. This does not indicate that the other three approaches discussed in the previous chapter are of less value. Learning potential measures, in particular, are likely to be of great use in South Africa as assessment tools. Conventional tests are substantially correlated with SES. Results of these tests can be misused and selection decisions made which discriminate against disadvantaged people. Learning potential may not be strongly correlated with SES; hence tests of learning potential may be of use in the development of fairer selection practices.

In their conventional form, learning potential tests produce a single global improvement score. This score is not interpretable in process terms. Learning potential could be used in a more process-orientated context by replacing the global pre-test and post-test measures of the conventional learning potential design with faceted tests. For experimental purposes, the design could be further elaborated by introducing more than one kind of instructional input. This highly modified design becomes in effect a special type of ATI design where pre-test and post-test are matched. (In a "normal" ATI design, the pre-test is a global aptitude measure.)

Error analysis has a number of uses. It can be used to improve accuracy of measurement in conventional testing. It can be used in a repeated measurement design to measure consistency of responses and estimate where a person is on a learning curve. It can also be used in the assessment of knowledge structure if item distractors are selected to represent specific types of misconceptions. Error analysis can be applied at various points during a learning process for diagnostic purposes.

Finally, the assessment of affective stylistic variables is probably best undertaken as part of the evaluation of metaprocessing (see the discussion at the end of section 4.2). The assessment of impulsivity and cognitive rigidity is of definite diagnostic importance. Impulsive and rigid styles are counterproductive to effective task execution. A low score on a conventional test could be caused by impulsive behaviour. As this type of behaviour is found frequently and can apparently be remediated fairly easily, it is important to have measures which can distinguish affective-stylistic processing problems from other cognitive deficits.

In First World countries, conventional testing has served the purposes of selection moderately well, although it has certainly not been without its critics. In education, conventional testing has been of relatively little worth. And in cross-cultural research into cognition, conventional testing has been of almost no worth.

One of the aims of this report has been to suggest ways in which these shortcomings can be redressed. In the process, a new role has been created for assessment. The tester who uses conventional assessment instruments in the normal selection context is analogous to a doctor who performs fitness tests but does not heal when he finds disease; he also gives no advice when he finds a discrepancy between a person's physical state and the physical demands which are placed upon him. The new testing models described in this report can be used to broaden the role of assessment to include functions which are compatible with the aims of a helping society.

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